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(54) **APPARATUS AND METHOD FOR VISUALIZING DIGITAL BREAST TOMOSYNTHESIS AND OTHER VOLUMETRIC IMAGES**

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CPC ..... **G06T 11/008** (2013.01); **G06T 7/0014** (2013.01); **G06T 2207/10112** (2013.01); **G06T 2207/30068** (2013.01); **G06T 2211/412** (2013.01)

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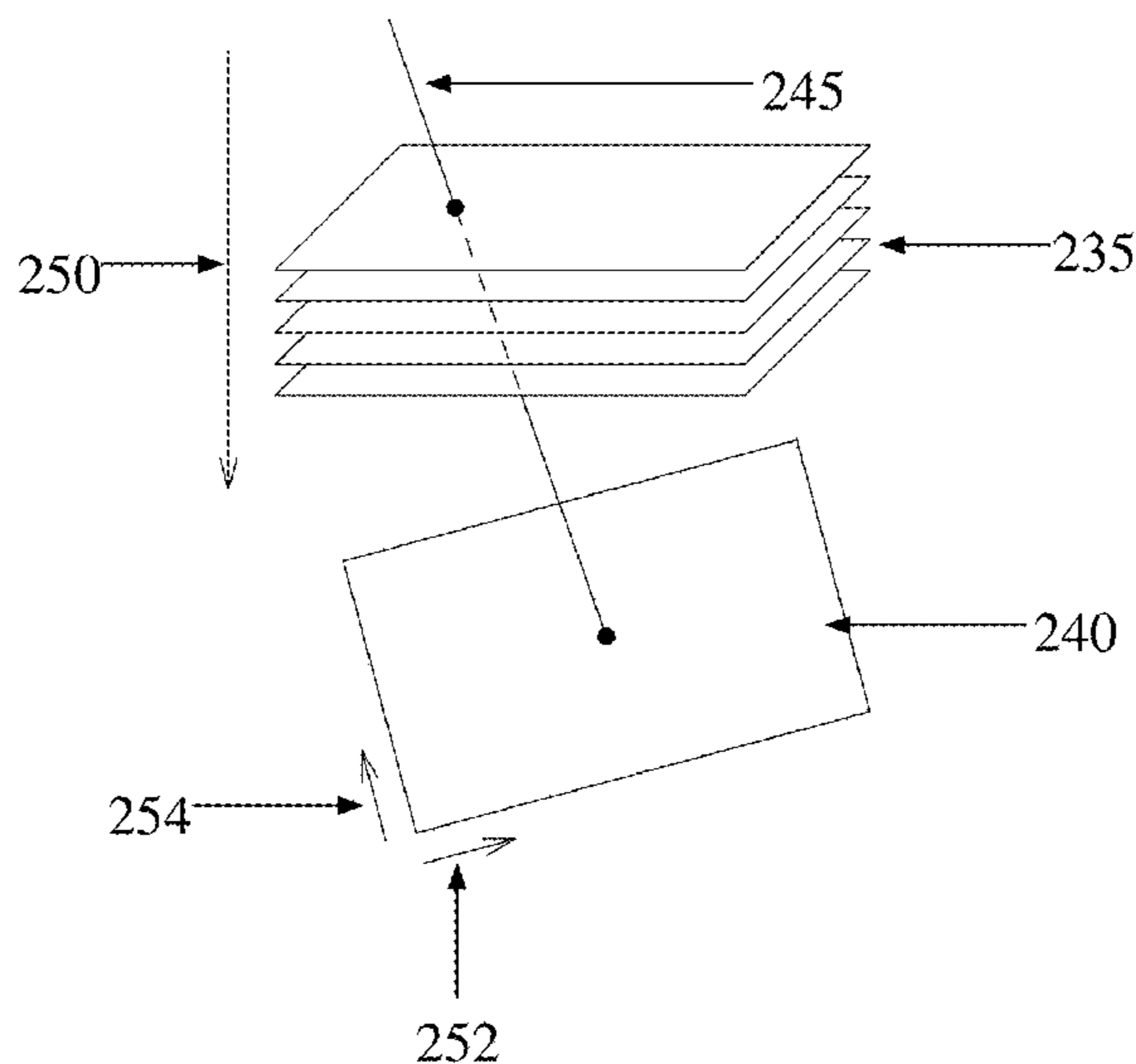
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(57) **ABSTRACT**

Digital Breast Tomosynthesis allows for the acquisition of volumetric mammography images. The present invention allows for novel ways of viewing such images to detect microcalcifications and obstructions. In an embodiment a method for displaying volumetric images comprises computing a projection image using a viewing direction, displaying the projection image and then varying the projection image by varying the viewing direction. The viewing direction can be varied based on a periodic continuous mathematical function. A graphics processing unit can be used to compute the projection image and bricking can be used to accelerate the computation of the projection images.

**20 Claims, 17 Drawing Sheets**



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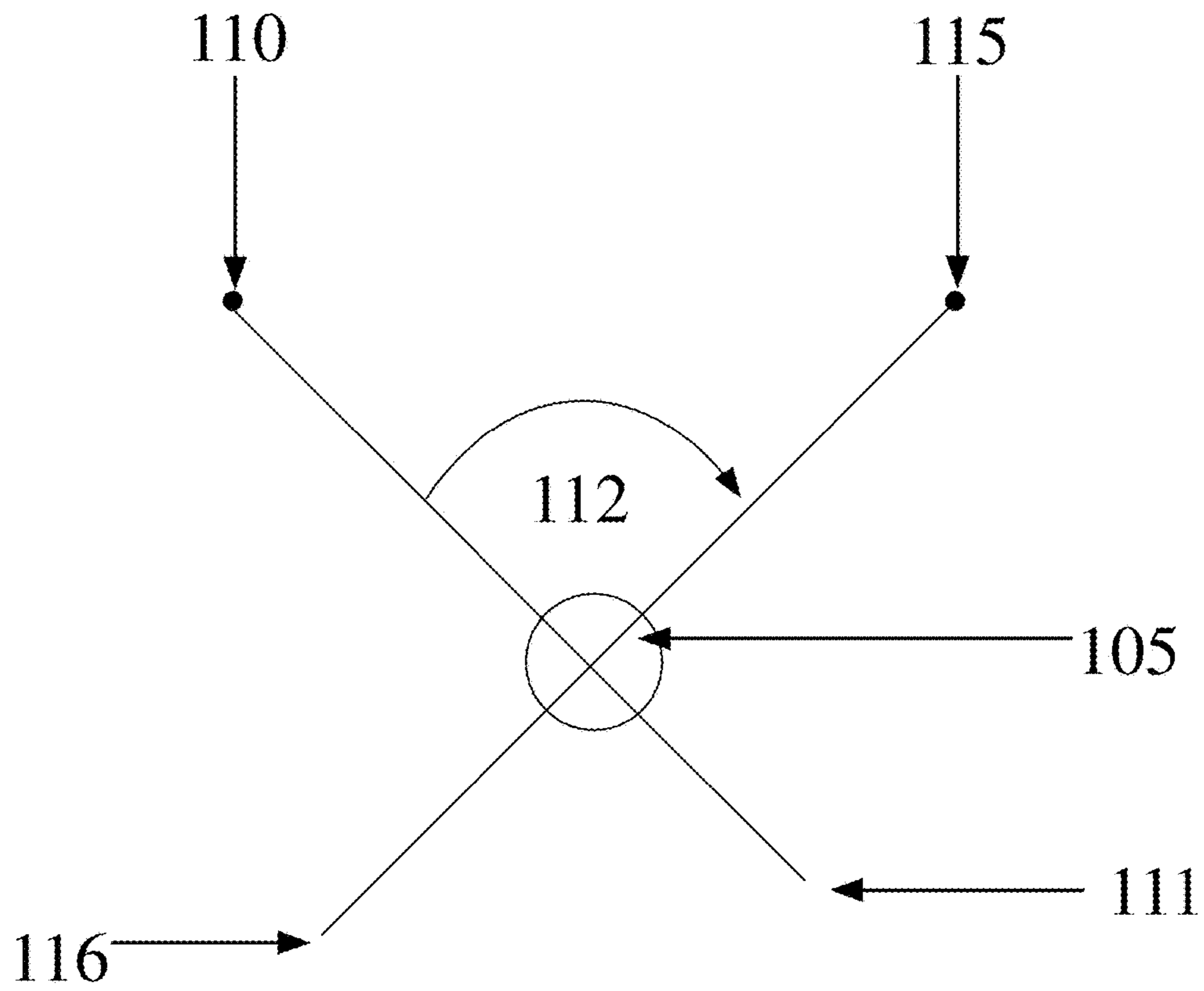
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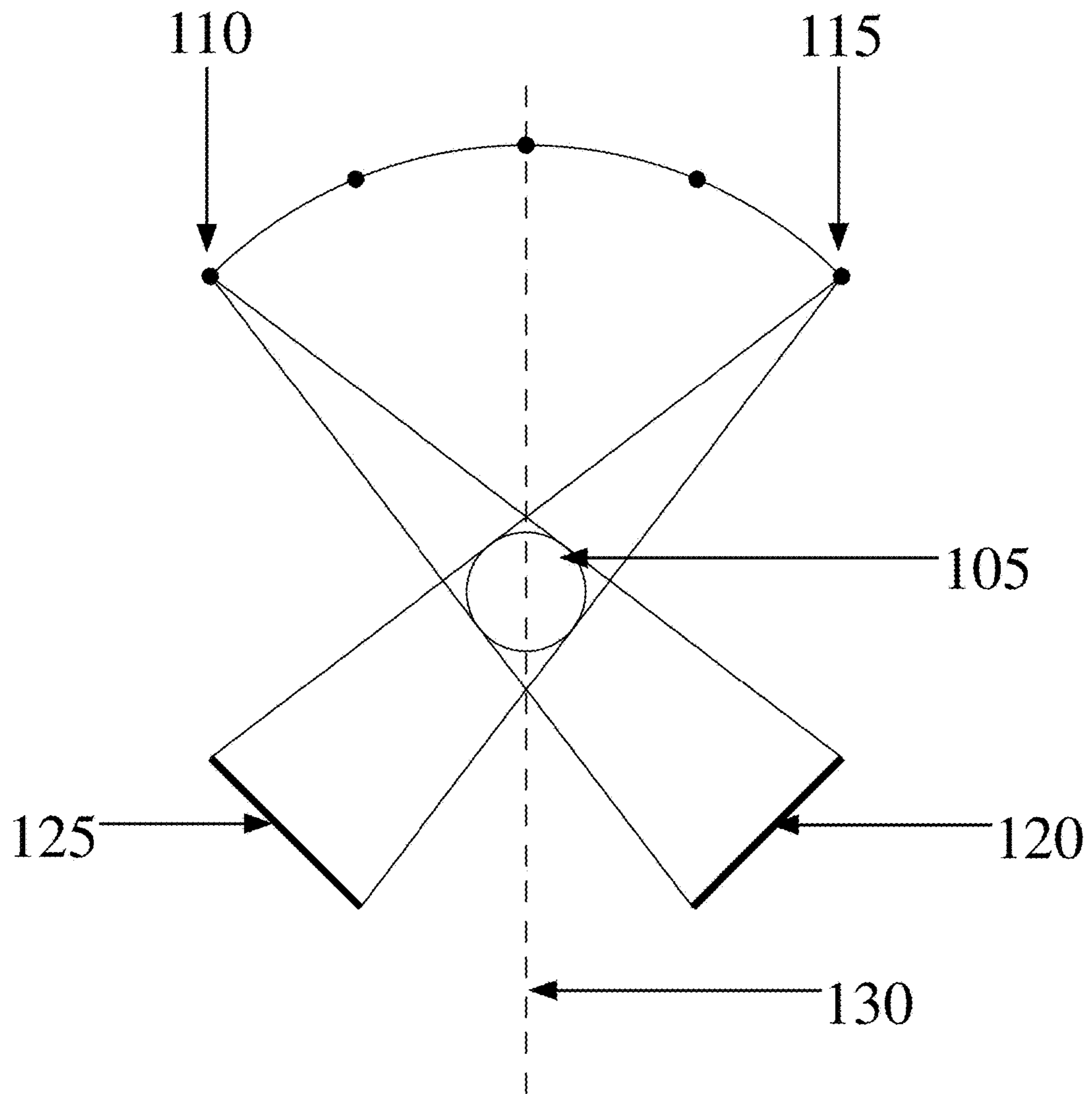
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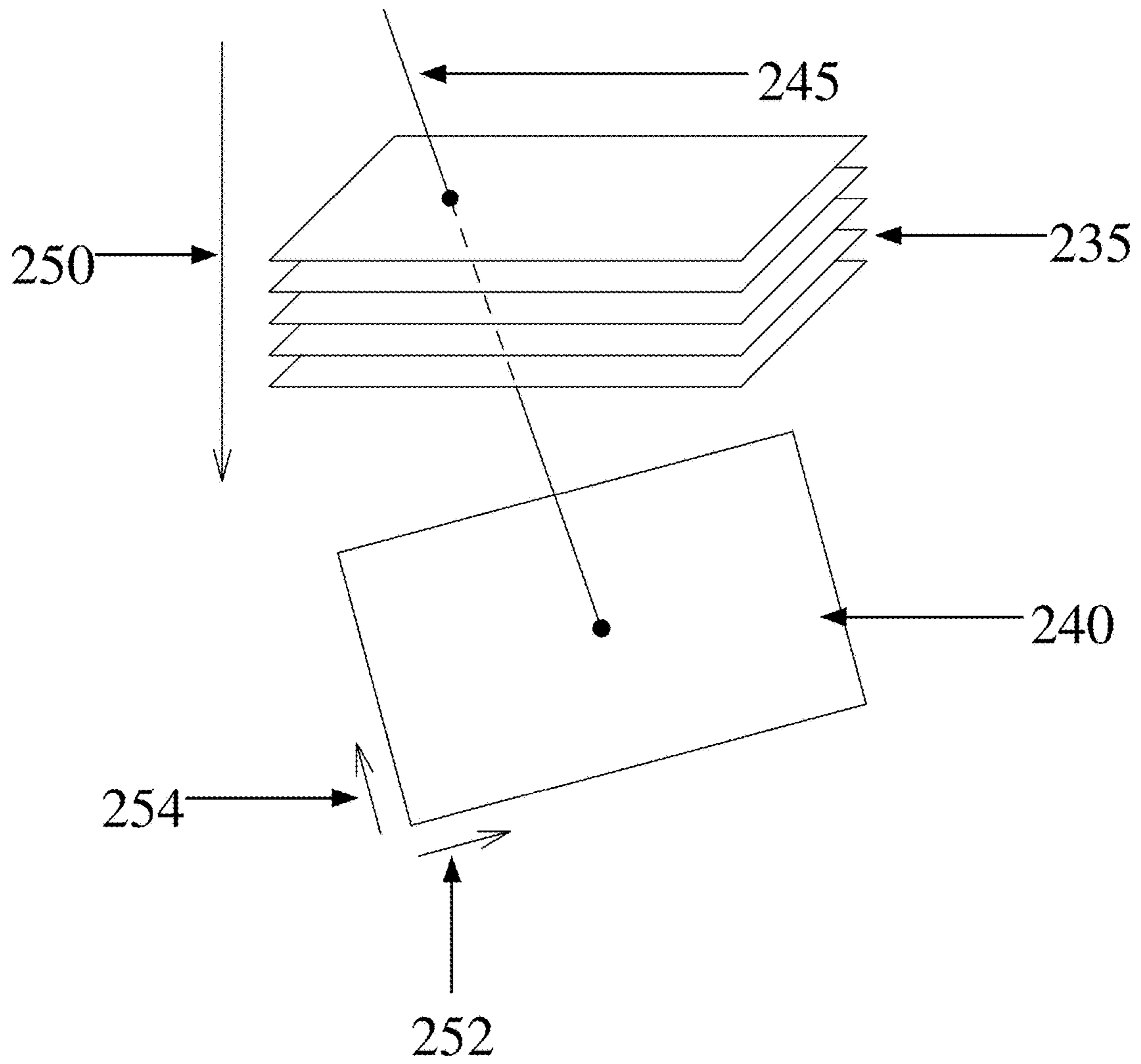


**Figure 1A**

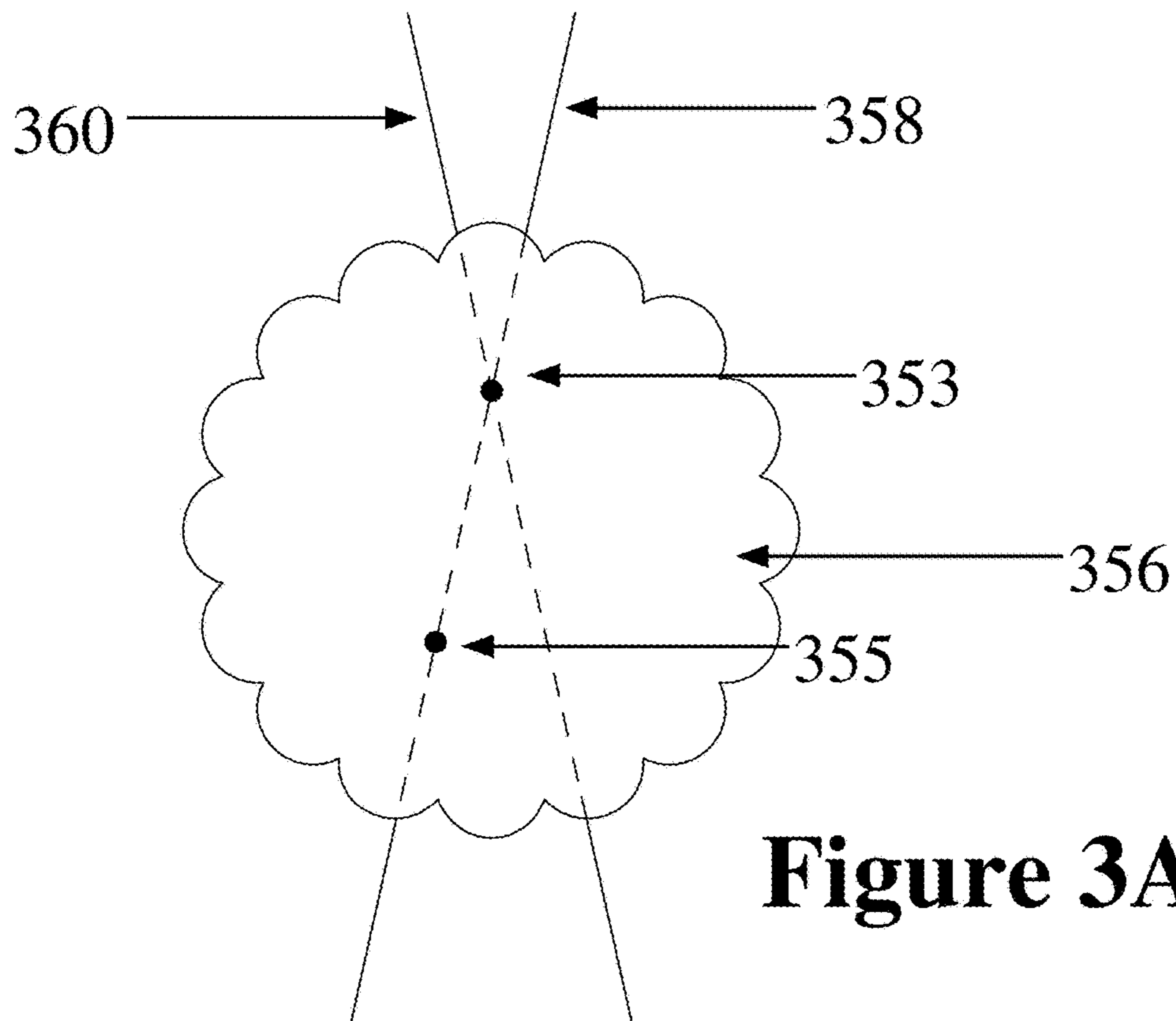


**Figure 1B**

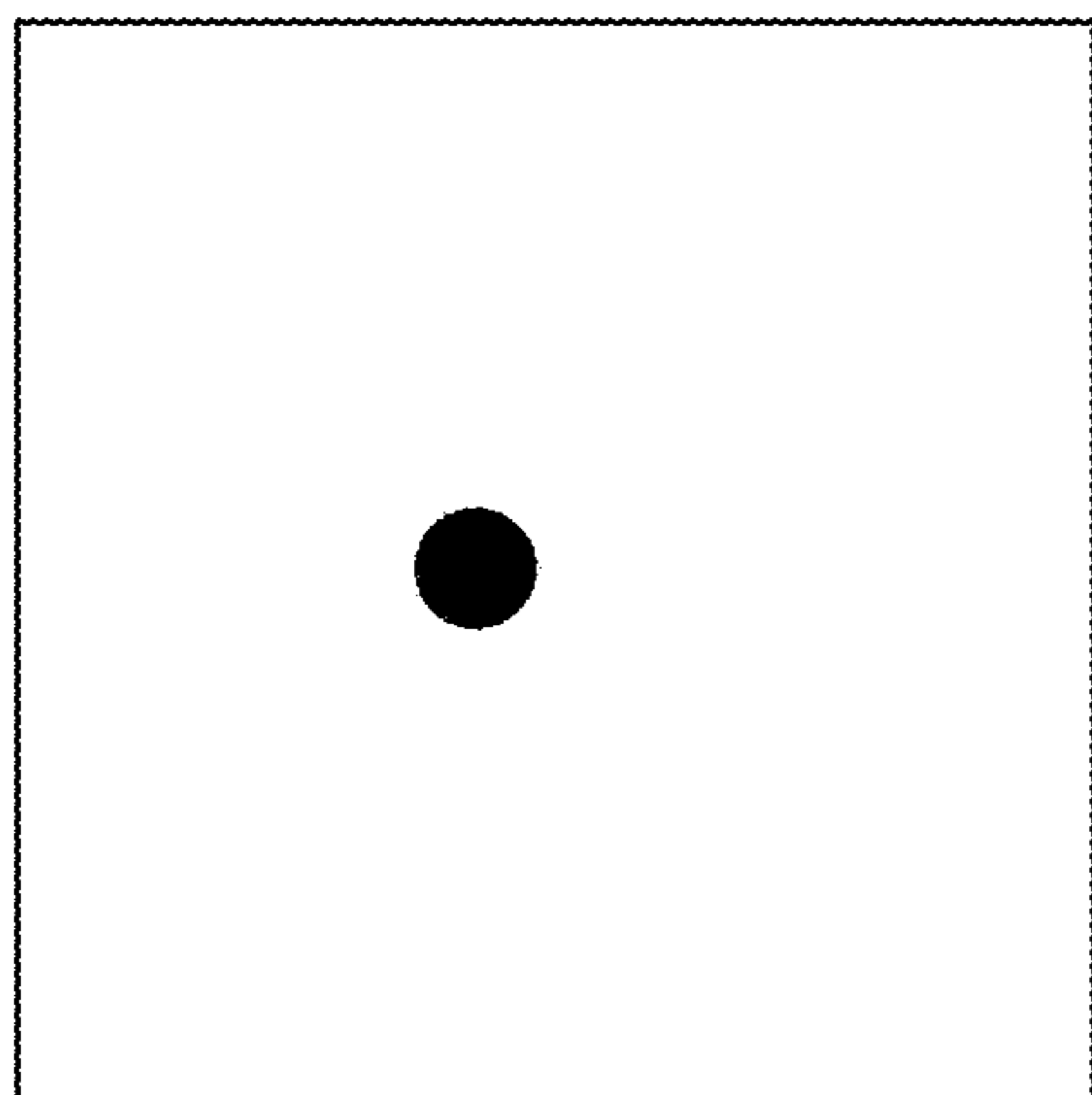




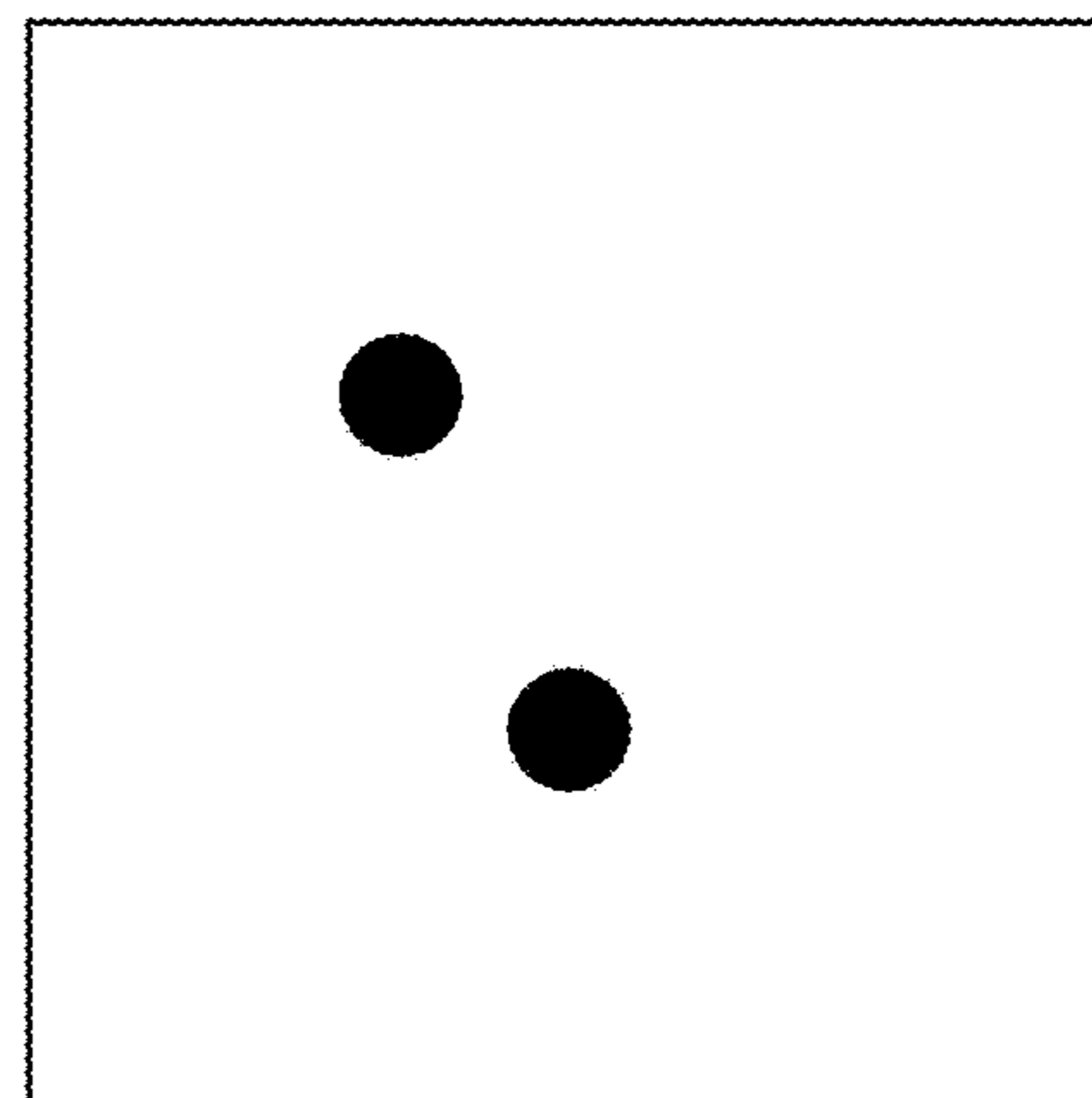
**Figure 2**



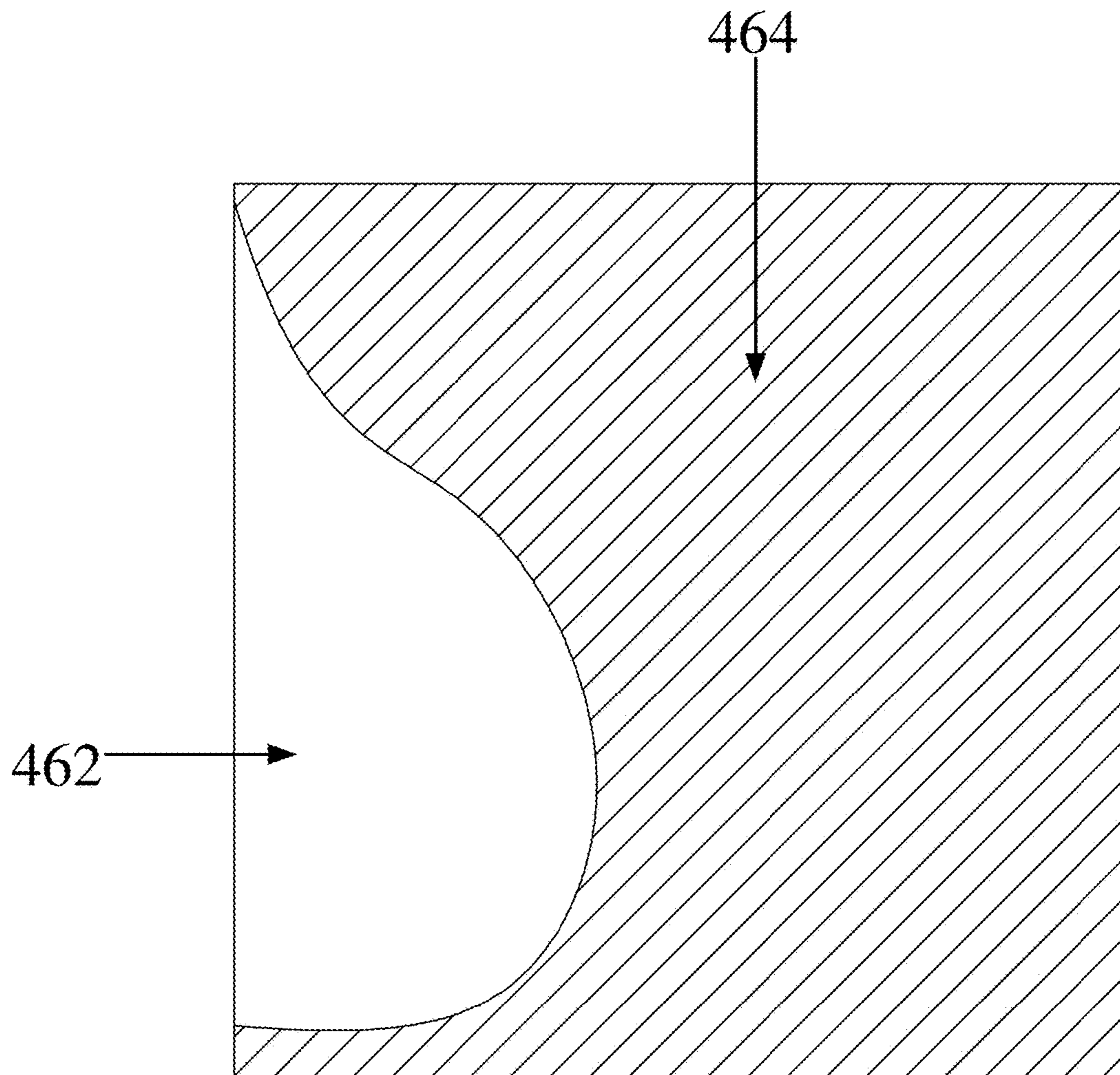
**Figure 3A**



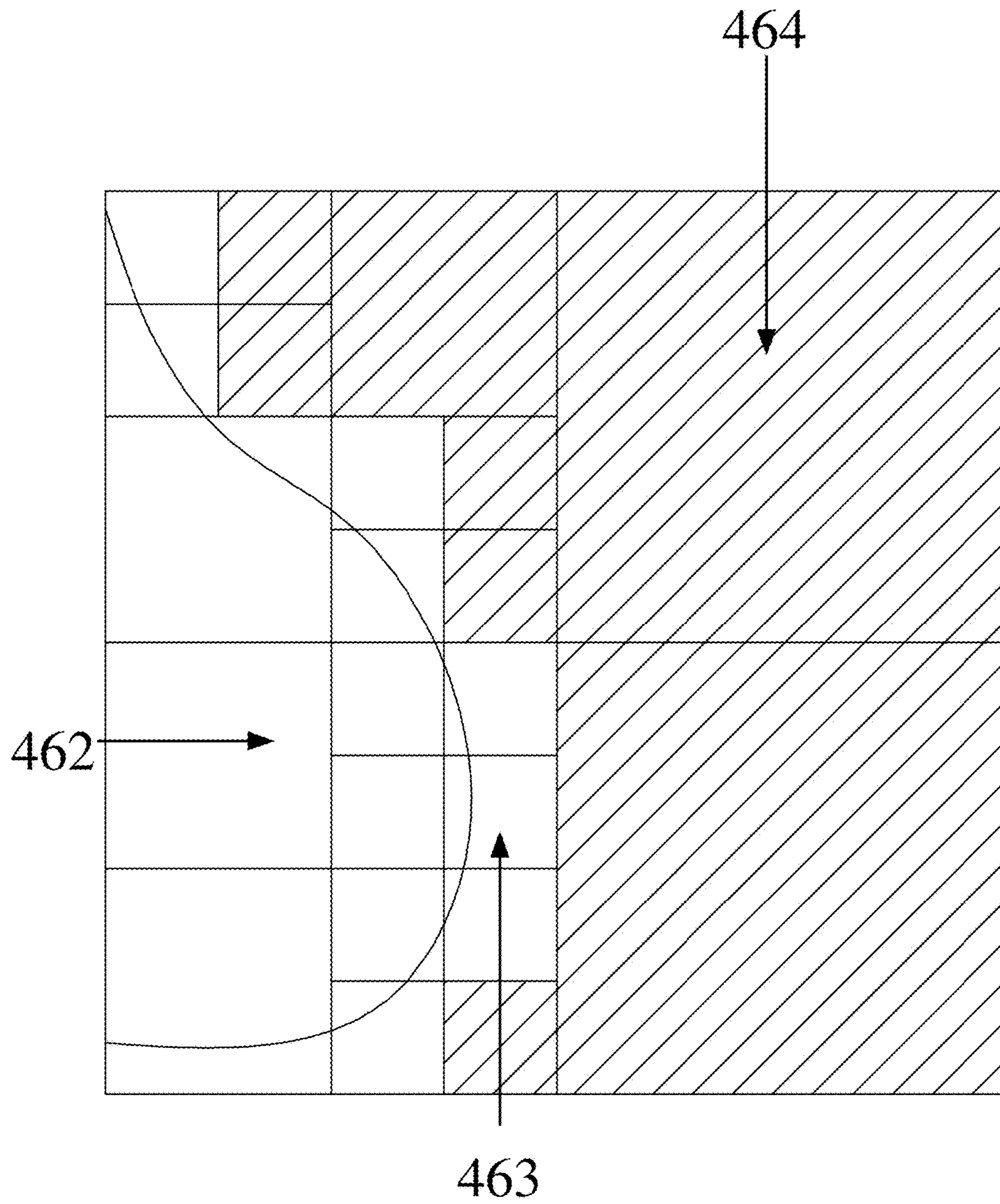
**Figure 3B**



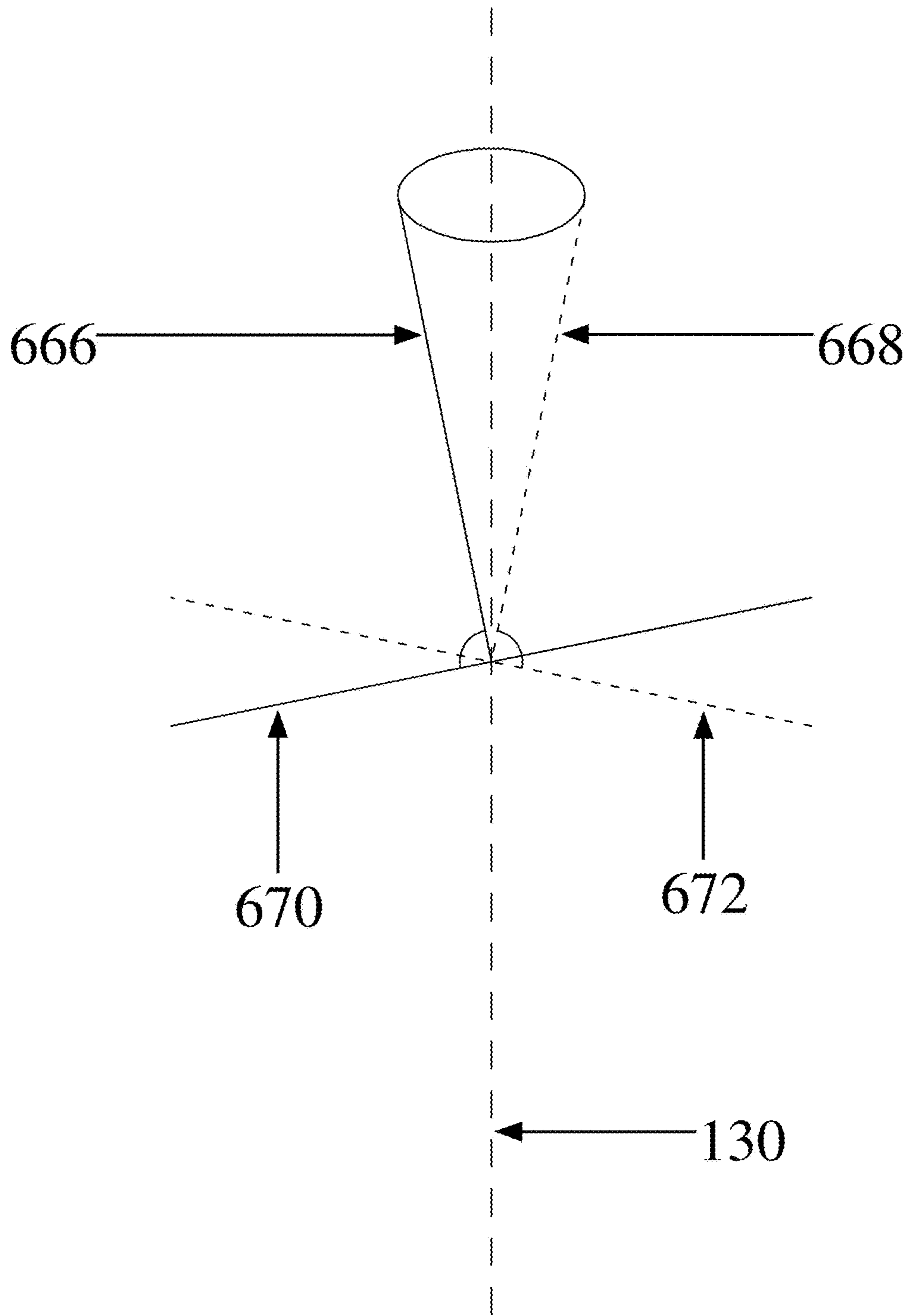
**Figure 3C**



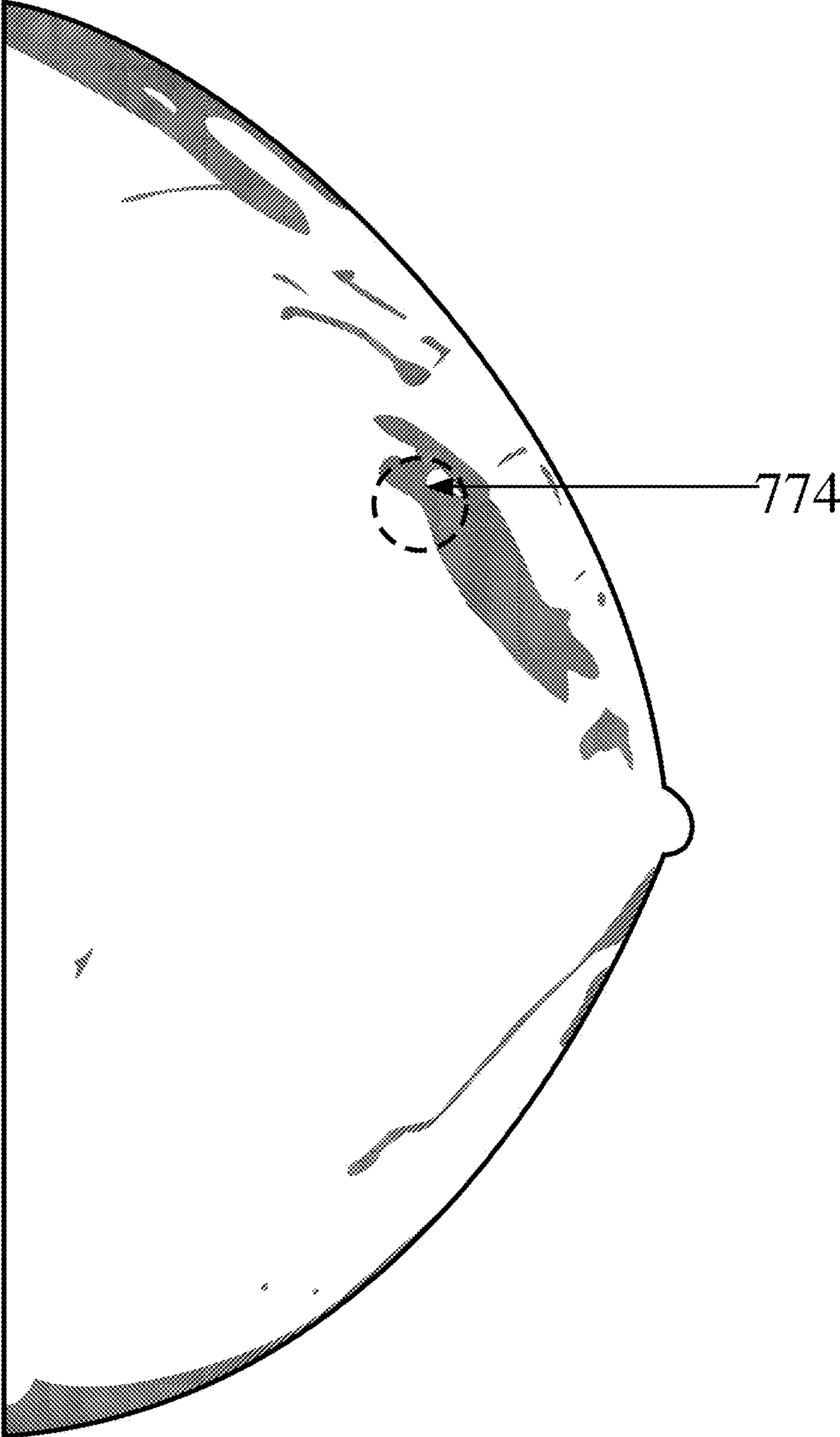
**Figure 4**



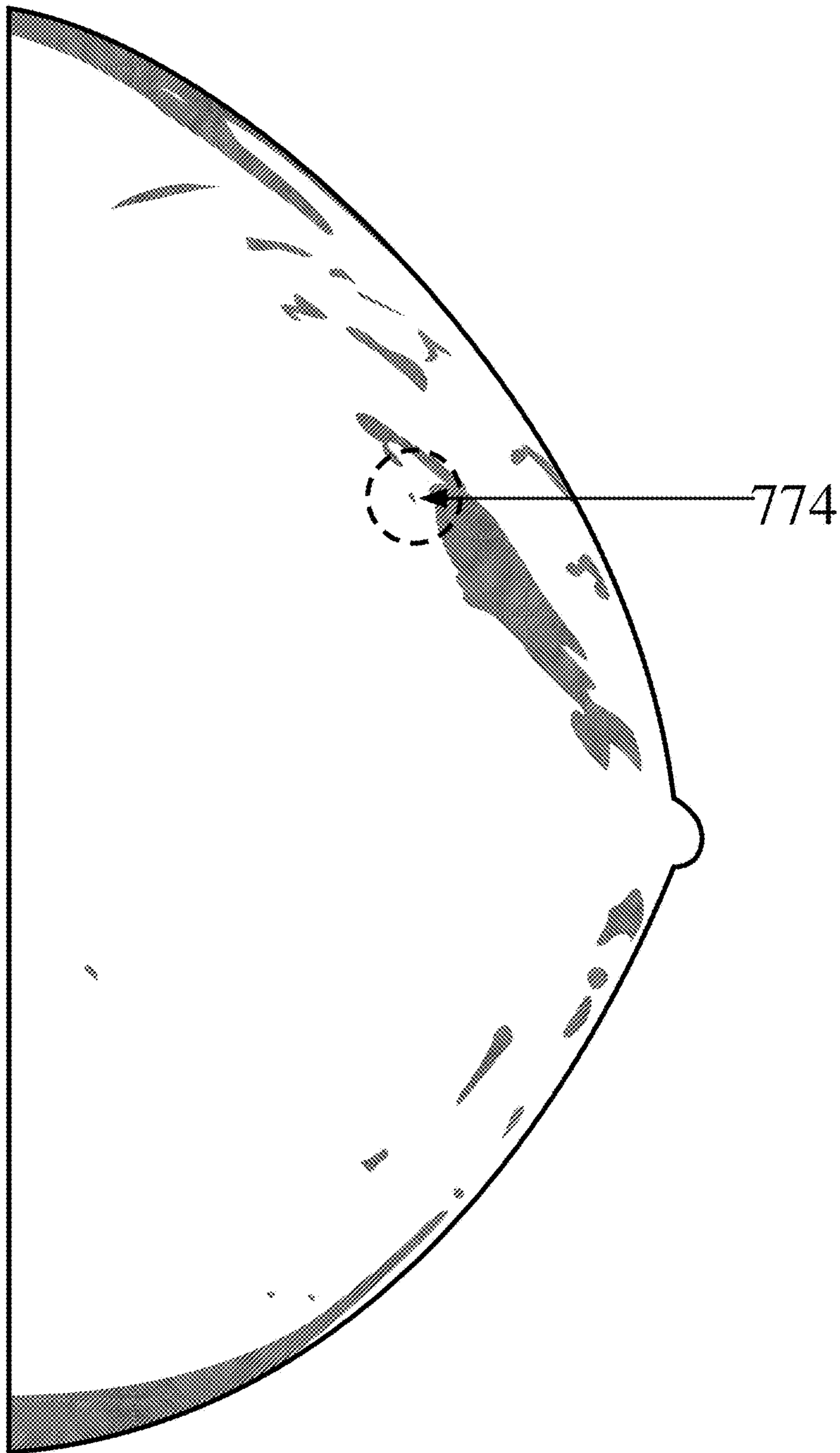
**Figure 5**



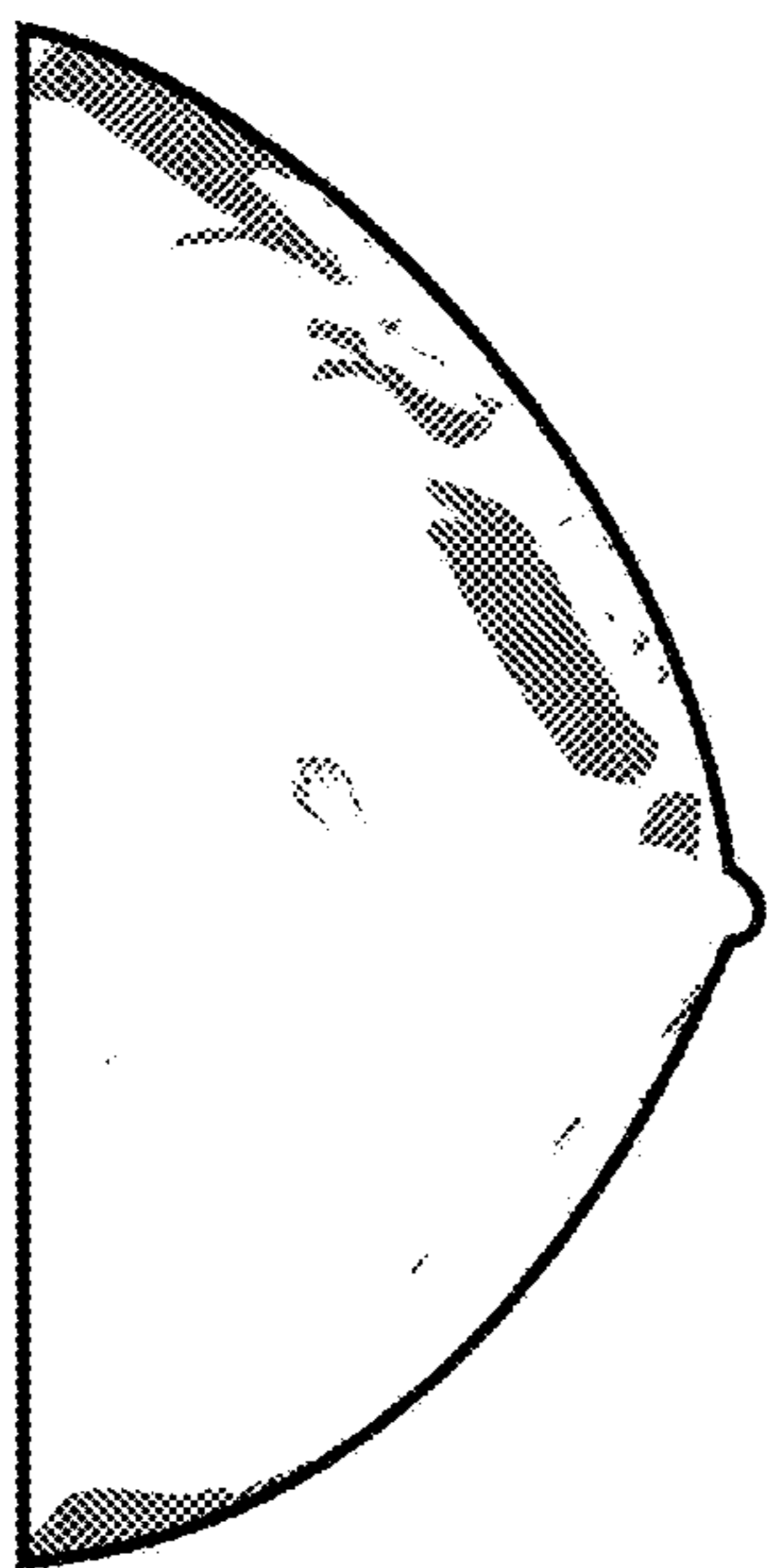
**Figure 6**



**Figure 7A**



**Figure 7B**



**Figure 8A**



**Figure 8B**



**Figure 8C**



**Figure 8D**

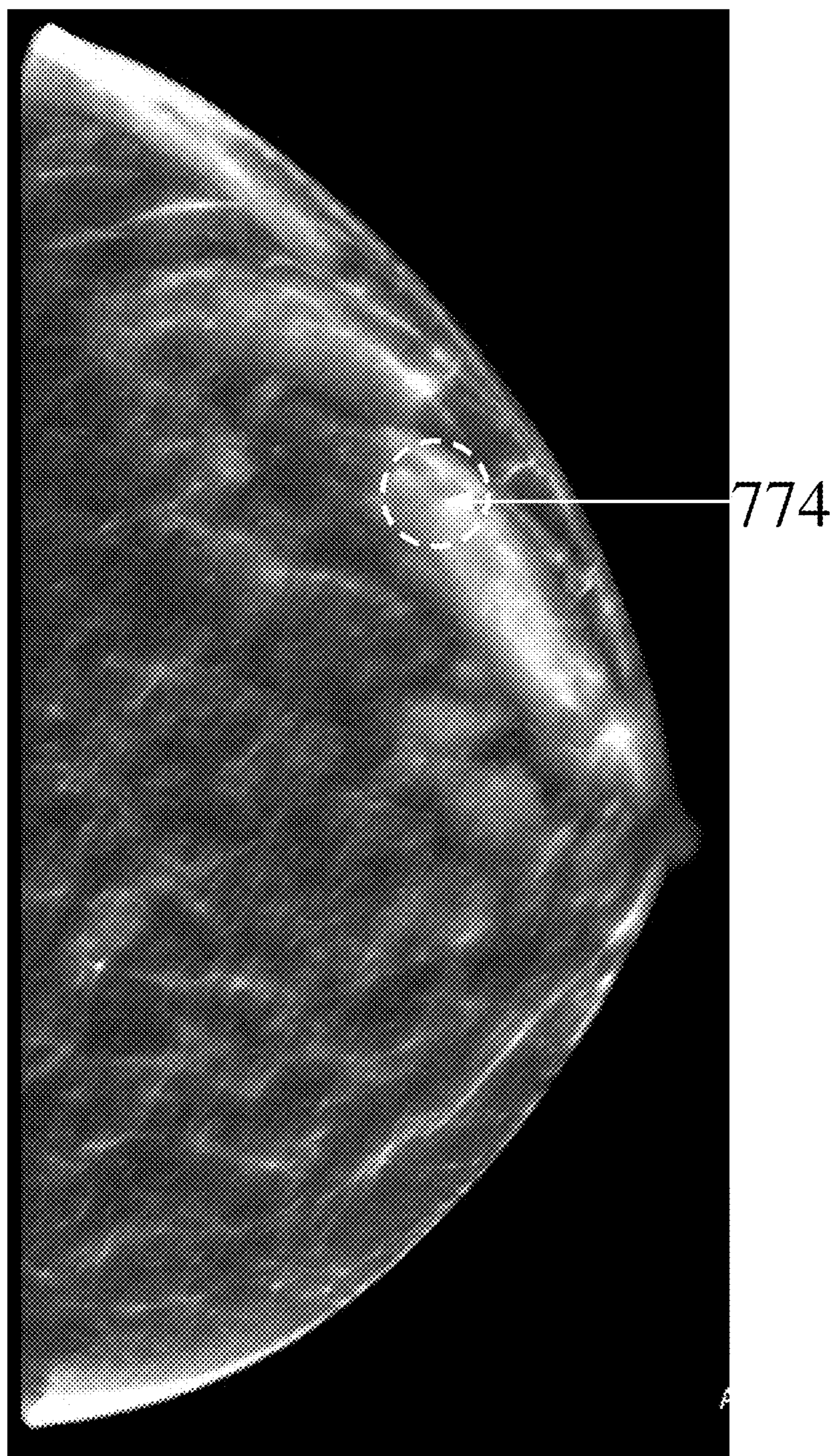




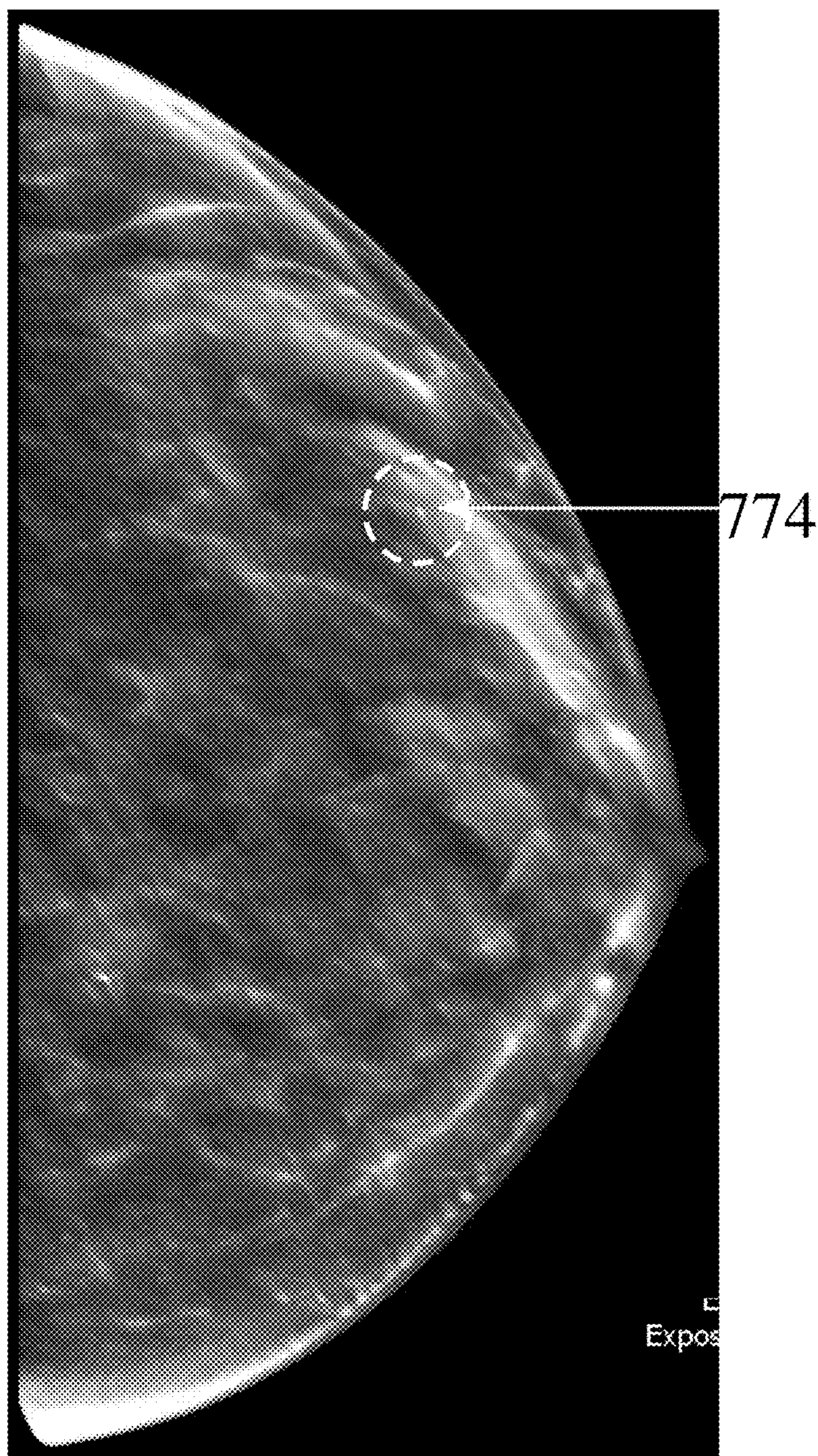
**Figure 9A**



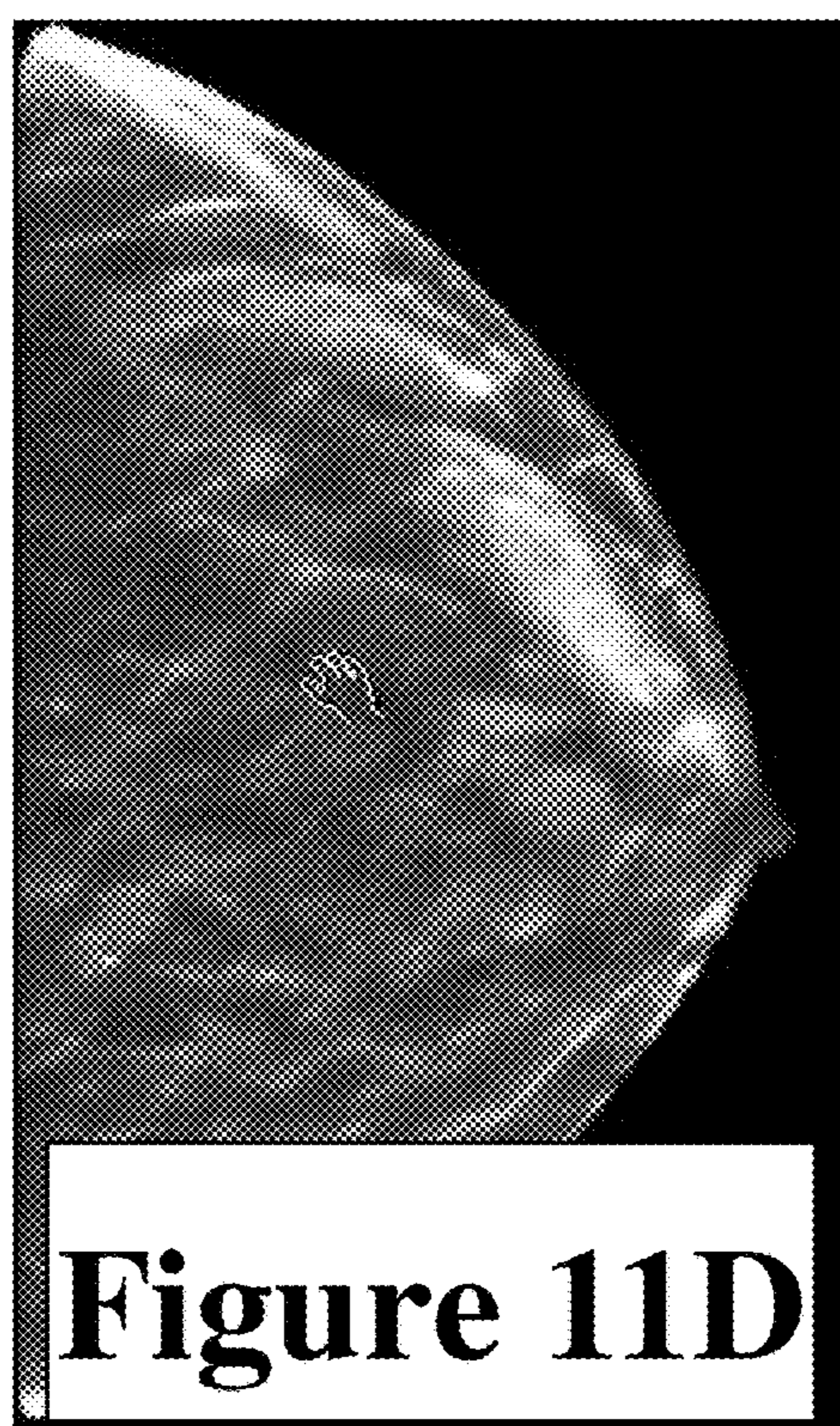
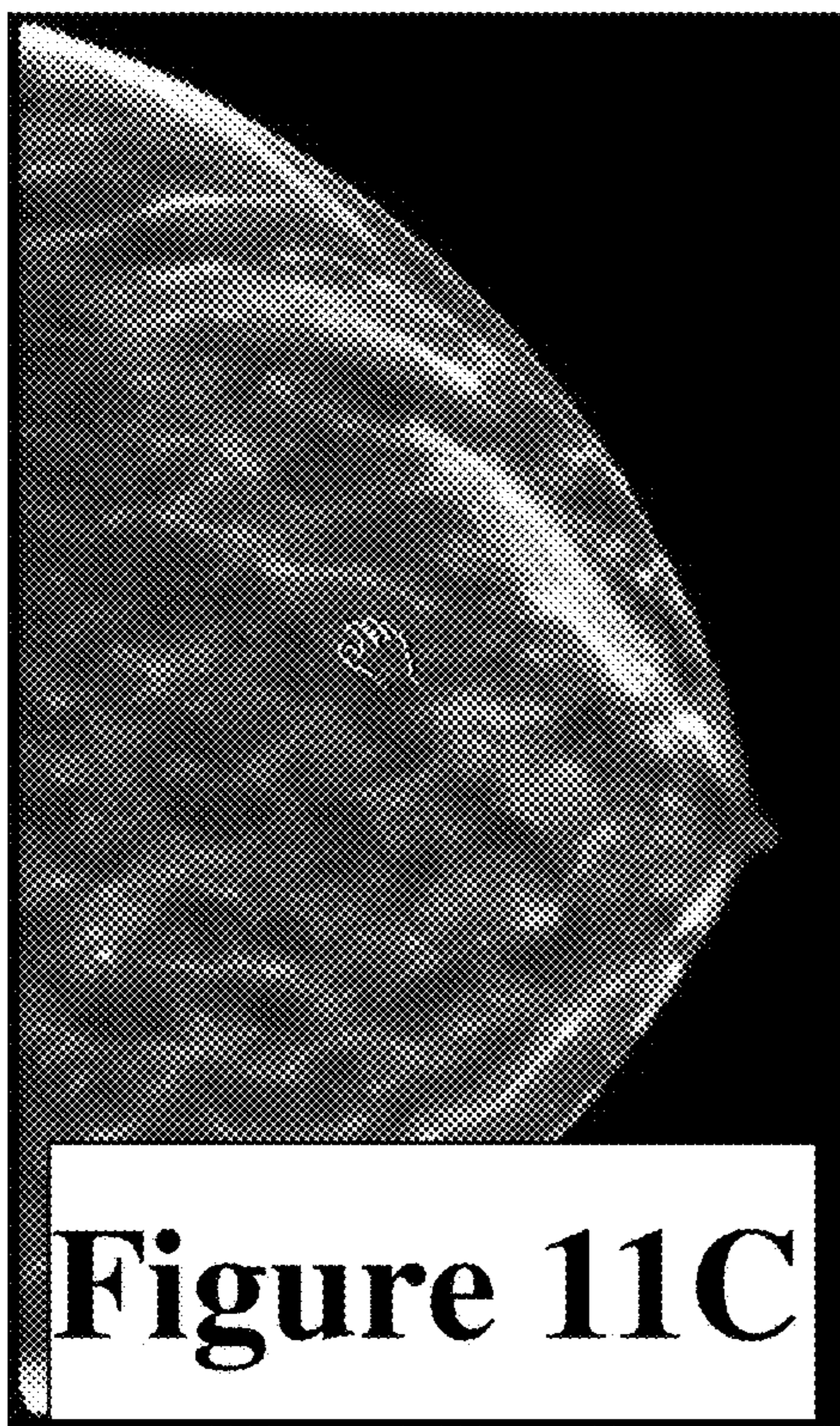
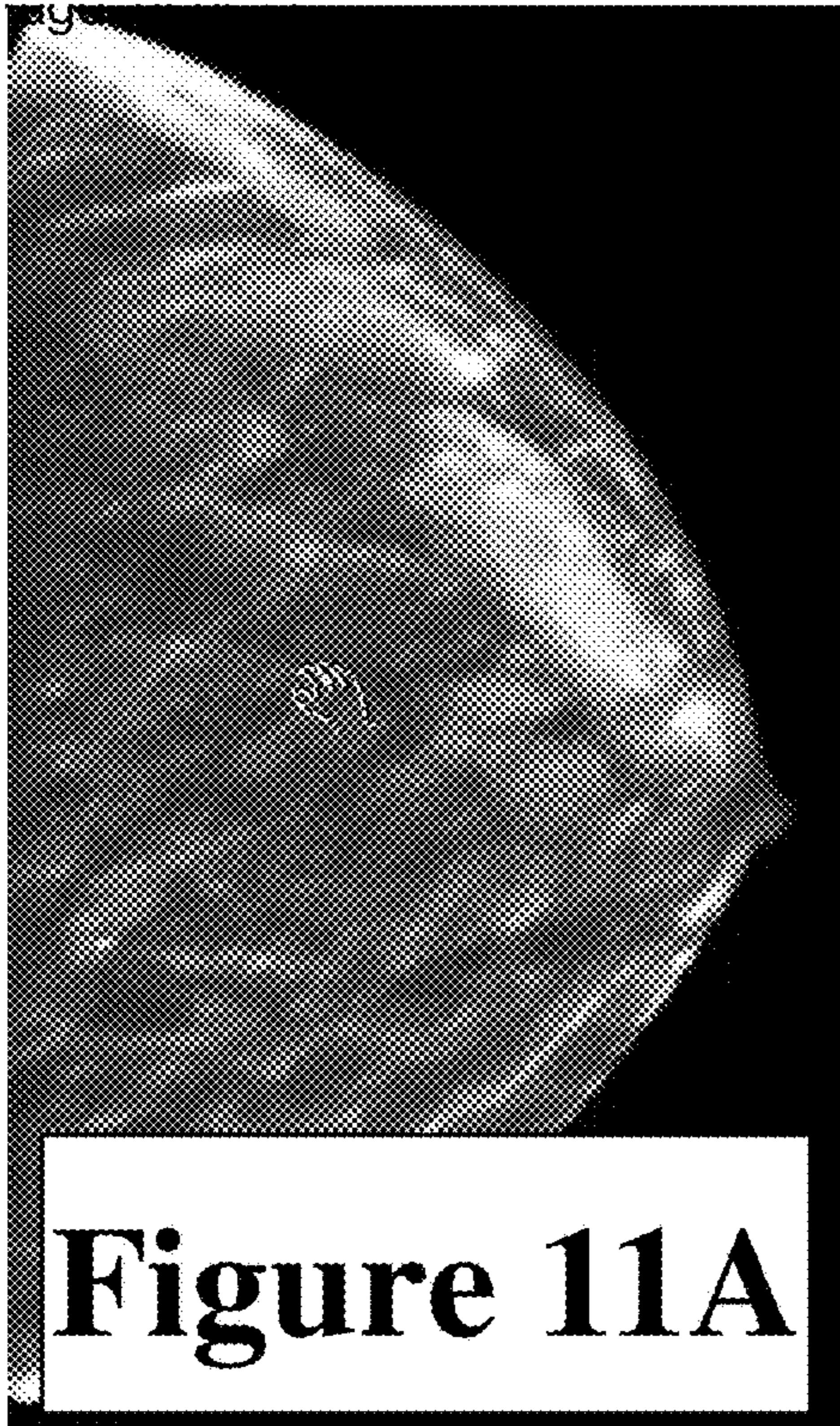
**Figure 9B**

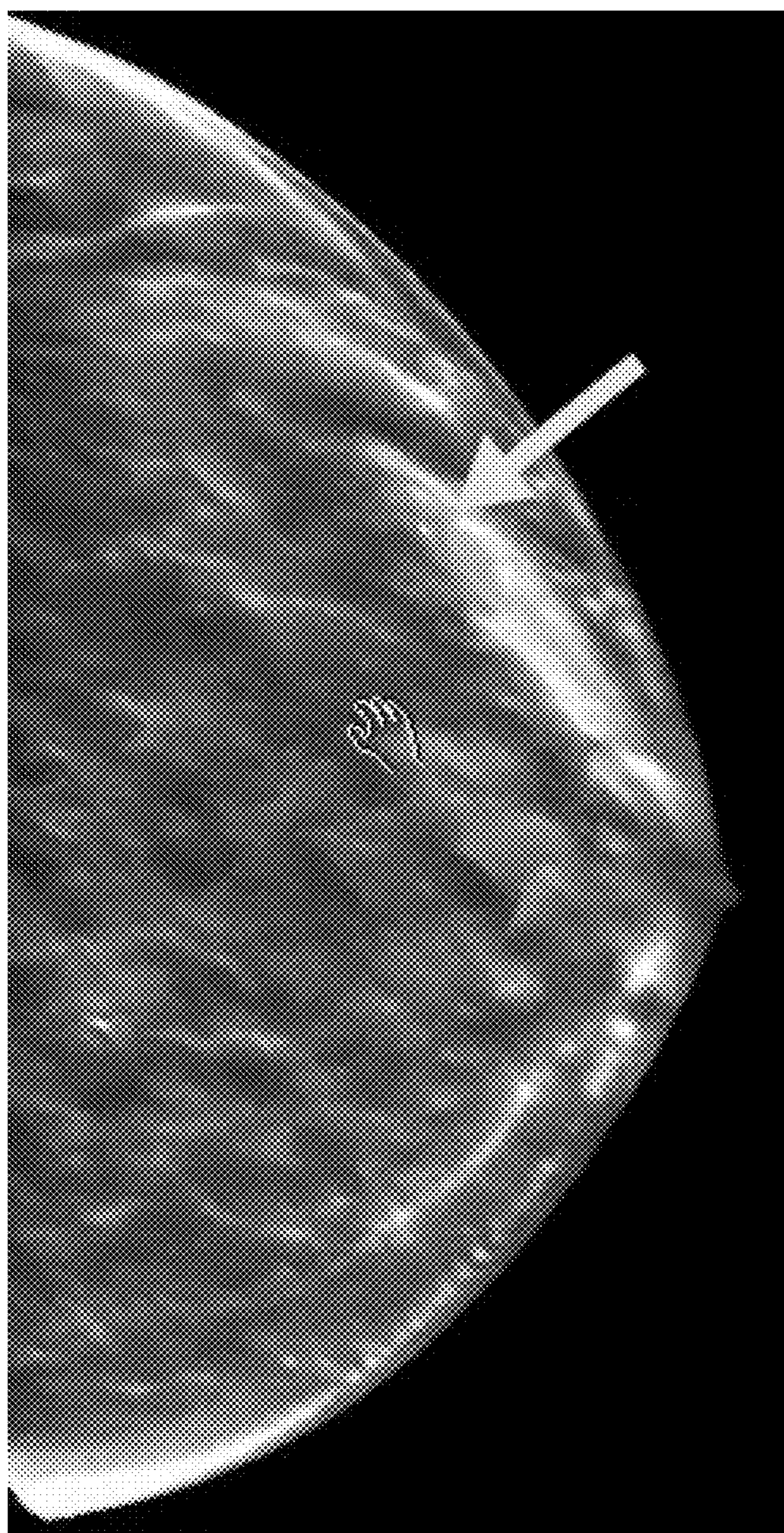


**Figure 10A**



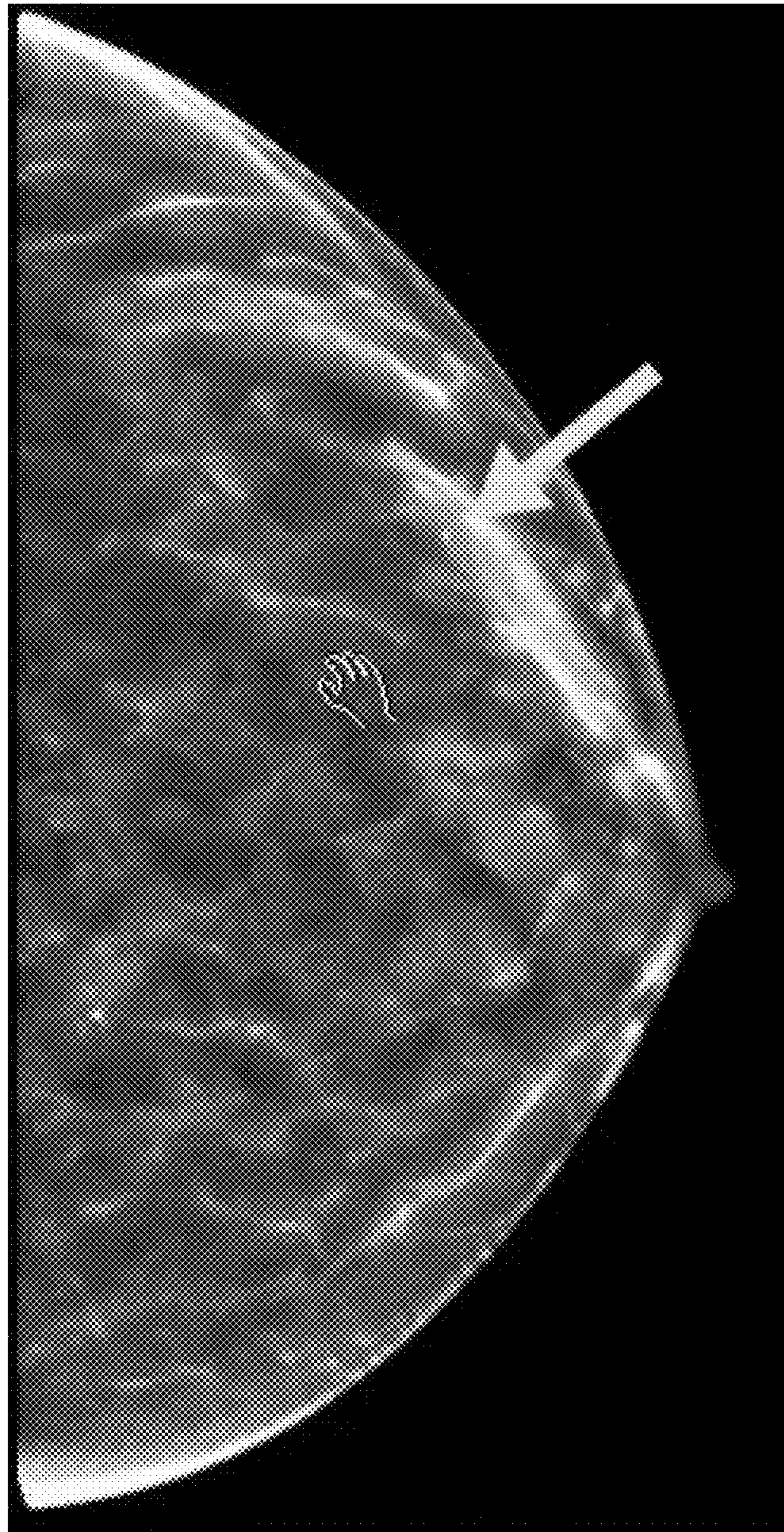
**Figure 10B**





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**Figure 12A**



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**Figure 12B**

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**APPARATUS AND METHOD FOR  
VISUALIZING DIGITAL BREAST  
TOMOSYNTHESIS AND OTHER  
VOLUMETRIC IMAGES**

PRIORITY CLAIM

This application claims priority to U.S. Provisional application No. 62/197,956 filed Jul. 28, 2015, the specification and drawings of which are herein expressly incorporated by reference in its entirety.

FIELD OF INVENTION

The invention pertains to novel ways of viewing volumetric images used for medical diagnosis.

BACKGROUND

Volumetric images play an increasingly important role in medical diagnosis including cancer treatments such as site directed chemotherapy and radiology. Volumetric images are being generated by a multitude of different devices, including Magnetic Resonance Imaging (MRI) scanners, see for example Nuclear magnetic resonance imaging apparatus, U.S. Pat. No. 4,534,358, or Computed Tomography (CT) scanners, see for example Patients' support installation for a tomographic X-ray apparatus, U.S. Pat. No. 3,974,388, or certain C-Arm devices, see for example C-Arm computerized tomography system, U.S. Patent Application Publication No. 2010/0284601.

A certain class of these modalities, such as the CT scanner computes the volumetric images from a series of 2D projections from different angles, see for example (i) Methods and Apparatus for Reconstruction of 3D Image Volumes From Projection Images, U.S. Pat. No. 7,876,944; (ii) Method of Reconstructing Computer Tomography (CT) Volumes Suitable for Execution on Commodity Central Processing Units (CPUS) and Graphics Processors, and Apparatus Operating in Accordance with those Methods, U.S. Pat. No. 7,778,392 and (iii) Method of Reconstructing Computer Tomography (CT) Volumes Suitable for Execution on Commodity Central Processing Units (CPUS) and Graphics Processors, and Apparatus Operating in Accordance with those Methods, U.S. Pat. No. 8,107,592, which references (i)-(iii) are herein expressly incorporated by reference in their entireties.

A recent advance in the field is the development of a Digital Breast Tomosynthesis (DBT) scanner which generates volumetric mammography images, see for example Integrated multi-mode mammography/tomosynthesis x-ray system and method, U.S. Pat. No. 7,869,563, which is herein expressly incorporated by reference in its entirety. Similar to CT or C-Arm devices, the DBT devices acquire a number of 2D X-Ray images, or 2D projections, from different angles. From these projections a volumetric image is computed.

SUMMARY OF THE INVENTION

In an embodiment of the present invention, a method for displaying volumetric images comprises computing a projection image using a viewing direction, displaying the projection image and then varying the projection image by varying the viewing direction. In an embodiment of the present invention, the viewing direction can be varied based on a periodic continuous mathematical function. In an embodiment of the present invention, a graphics processing

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unit (GPU) can be used to compute the projection image and bricking can be used to accelerate the computation of the projection images. In another embodiment of the present invention, a sequence of projections covering one period can be rendered, cached and then played back one or more times, where the rendering is carried out on a server and the caching and play back is carried out on a client computer. A render server program is described in U.S. application Ser. No. 13/831,967, entitled "Multi-User Mult-GPU Render Server Apparatus and Methods", which was filed Mar. 15, 2013 is herein expressly incorporated by reference in its entirety. A rule based render server program is described in "Method and System for Rule-Based Display of Sets of Images" which issued as U.S. Pat. No. 8,976,190 on Mar. 10, 2015, and is herein expressly incorporated by reference in its entirety. In an alternative embodiment of the present invention, the viewing direction can be varied based on user input. In a different embodiment of the present invention, a system that displays two or more volumetric images by computing a projection image of each of the volumetric images, using the same viewing direction  $\underline{v}$  for each volumetric image, displaying each projection images, and varying the projection image by varying the viewing direction, where the varied viewing direction is changed in the same way for each of the projections. In an embodiment of the present invention, the volumetric images are computed from a number of 2D X-Ray images, or 2D projections, from different angles generated by a DBT device. In an embodiment of the present invention, volumetric mammography images are displayed. In an alternative embodiment of the present invention, volumetric images are computed from a number of 2D X-Ray images generated by angiography. In an embodiment of the present invention, the volumetric cerebral angiography images of the human brain are displayed. In another alternative embodiment of the present invention, volumetric images are computed from a confocal microscope using antibody staining. In an embodiment of the present invention, volumetric cell tissue generated by the confocal microscope is displayed.

BRIEF DESCRIPTION OF THE DRAWINGS

This invention is described with respect to specific embodiments thereof. Additional features can be appreciated from the Figures in which:

FIG. 1A shows the specimen imaged using an X-Ray source from two positions spanning an angular range;

FIG. 1B shows the specimen imaged using an X-Ray source and an X-Ray detector from a multitude of positions. The positions span a certain angular range that is defined by the physical constraints of the machine and the patient's position;

FIG. 2 illustrates the calculation of a projection P from the volumetric image I, where the projection is defined by the viewing direction  $\underline{v}$ , which defines the Projection plane, according to an embodiment of the invention;

FIG. 3A shows a specimen with two areas of increased density, according to an embodiment of the invention;

FIG. 3B shows the two areas in FIG. 3A projected to the same spot in the projection Image, according to an embodiment of the invention;

FIG. 3C shows the two areas in FIG. 3A projected to different spots in the projection Image, according to an embodiment of the invention;



FIG. 4 shows how only a subset of the acquisition volume is covered by the specimen, while other areas (hatched) only contain background pixels, according to an embodiment of the invention;

FIG. 5 shows the volume subdivided into sub-volumes, according to an embodiment of the invention;

FIG. 6 illustrates the dynamic variation of the viewing direction  $\underline{y}$  according to Equation 2, according to an embodiment of the invention;

FIG. 7A shows an artists impression of an image of a human breast computed from a number of images recreated from a specific angle where a micro calcification is occluded by denser breast tissue, according to an embodiment of the invention;

FIG. 7B shows an artists impression of an image of a human breast taken from a different angle to that shown in FIG. 7A, where the micro calcification is visible and not occluded by the denser breast tissue, according to an embodiment of the invention;

FIG. 8A shows an artists impression of a screen dump of a video image at approximately the two (2) second time point, where the video shows a dynamic comparison of a human breast computed from a number of images recreated as the viewing direction is changed, where micro calcification occluded by denser breast tissue can be revealed, according to an embodiment of the invention;

FIG. 8B shows an artists impression of a screen dump of a video image at approximately the five (5) second time point, where the video shows a dynamic comparison of a human breast computed from a number of images recreated as the viewing direction is changed, where micro calcification occluded by denser breast tissue can be revealed, according to an embodiment of the invention;

FIG. 8C shows an artists impression of a screen dump of a video image at approximately the nine (9) second time point, where the video shows a dynamic comparison of a human breast computed from a number of images recreated as the viewing direction is changed, where micro calcification occluded by denser breast tissue can be revealed, according to an embodiment of the invention;

FIG. 8D shows an artists impression of a screen dump of a video image at approximately the twelve (12) second time point, where the video shows a dynamic comparison of a human breast computed from a number of images recreated as the viewing direction is changed, where micro calcification occluded by denser breast tissue can be revealed, according to an embodiment of the invention;

FIG. 9A shows the artists impression of a screen dump of a video image at approximately the five (5) second time point shown in FIG. 8B, according to an embodiment of the invention;

FIG. 9B shows the artists impression of a screen dump of a video image at approximately nine (9) second time point shown in FIG. 8C, according to an embodiment of the invention;

FIG. 10A shows the image of a human breast represented in FIG. 7A, according to an embodiment of the invention;

FIG. 10B shows the image of the human breast taken from a different angle to that shown in FIG. 10A, represented in FIG. 7B, according to an embodiment of the invention;

FIG. 11A shows a screen dump from the mp3 video at approximately the two (2) second time point, represented in FIG. 8A, according to an embodiment of the invention;

FIG. 11B shows a screen dump from the mp3 video at approximately the five (5) second time point, represented in FIG. 8B, according to an embodiment of the invention;

FIG. 11C shows a screen dump from the mp3 video at approximately the nine (9) second time point, represented in FIG. 8C, according to an embodiment of the invention;

FIG. 11D shows a screen dump from the mp3 video at approximately the twelve (12) second time point, represented in FIG. 8D, according to an embodiment of the invention;

FIG. 12A shows the screen dump from the mp3 video at approximately the five (5) second time point, as represented in FIG. 9A, according to an embodiment of the invention; and

FIG. 12B shows the screen dump from the mp3 video at approximately the nine (9) second time point, as represented in FIG. 9B, according to an embodiment of the invention.

## DESCRIPTION OF THE INVENTION

### Definitions

The transitional term ‘comprising’ is synonymous with “including,” “containing,” or “characterized by,” is inclusive or open-ended and does not exclude additional, unrecited elements or method steps.

The transitional phrase ‘consisting of’ excludes any element, step, or ingredient not specified in the claim, but does not exclude additional components or steps that are unrelated to the invention such as impurities ordinarily associated with a composition.

The transitional phrase ‘consisting essentially of’ limits the scope of a claim to the specified materials or steps and those that do not materially affect the basic and novel characteristic(s) of the claimed invention.

The term ‘bandwidth’ and ‘send bandwidth’ refer to various bit-rate measures, representing the available or consumed data communication resources expressed in bits per second or multiples of it.

The phrase ‘adaptive bandwidth management’ means methods that continuously adjust the amount of data that is sent into a network per time in order to avoid or reduce network congestion and transfer delay.

The term ‘client-server’ refers to a computer system that selectively shares its resources with ‘clients’. A ‘client’ is a computer or computer program that initiates contact with a ‘client-server’ or ‘server’ in order to make use of the server resources. A client-server can be especially useful to undertake volume rendering tasks. Such a server can have one or more graphics processing units. Further, by sharing the server’s computer resources, multiple clients can access and use the server resources at the same time. Because a computer does a limited amount of work at any moment, a time-sharing system must quickly prioritize its tasks to accommodate the clients. Clients and servers exchange messages in a request-response messaging pattern: The client sends a request, and the server returns one or multiple responses, synchronously or asynchronously.

The term ‘video’ means the display of three (3) or more 2-D projection images where there is a time delay between the first 2-D projection image and a second 2-D projection image and a time delay between the second 2-D projection image and a third 2-D projection image. A video may be displayed using a number of formats including avi, flv, H.262, H.263, H.264, m4v, mov, MPEG-1, MPEG-1 Part 2, MPEG-2, MPEG-4 Part 2, nsv, ogv, roq, vp6, vp8, vp9, webm, and wmv.

The phrase ‘host computer’ means a server or other processor with associated memory. In an embodiment of the invention, a host computer is enabled to provide measured 2-D projection images to a client.

The term 'caching' means storing in memory. A generated projection image from a volumetric image can be cached in one or both a client associated memory and a server associated memory, where the memory can be accessed rapidly by either the client processor or the server processor respectively.

The phrase 'measured 2-D projection image' means a two-dimensional (2-D) scan of biological tissue produced by forward-projection or back-projection of medical imaging equipment as described in U.S. Pat. No. 8,107,592 to A. Berman, and U.S. Pat. No. 7,876,944 to D Stalling et al.

The phrase 'volumetric image' refers to a three-dimensional (3-D) representation reconstructed from the data produced from a series of measured 2-D projection images or other 2-D representations of a tissue, an organ or an entity.

The term 'reconstruction' means generating a 3-D volumetric image based on a plurality of measured 2-D projection images. The phrase 'reconstruction of a volumetric image' means calculating a 3-D volumetric image based on a plurality of measured 2-D projection images.

The term 'generated' means constructing one or more generated 2-D projection images from a 3-D volumetric image. The phrase 'generating an image' or 'generating a plurality of images' means constructing one or more generated 2-D projection images from a 3-D volumetric image. In an embodiment of the invention, the one or more generated 2-D projection images can be generated at different viewing directions.

The phrase 'viewing direction' means the line constructed passing through a viewing position to an object. As the designated position changes, the viewing direction changes. As shown in FIG. 1A a first viewing direction **111** is generated by the line between position **110** and the object **105**. A second viewing direction **116** is generated by the line between position **115** and the object **105**. The angle ( $\theta$ ) between the first viewing direction **111** and the second viewing direction **112** increases from 0 to  $\theta$ . The smallest viewing direction is when the angle=0. The largest viewing direction is when the angle= $\theta$ .

The phrase 'equivalent viewing direction' means the same viewing direction in the absence of physiologic changes in the tissue or an equivalent viewing direction when physiologic changes have occurred or a comparable tissue is utilized, where the equivalent viewing direction can compensate for changes in the tissue in the body with time and/or can compensate for the symmetry and asymmetry of different tissue in the body. The equivalent viewing direction can be used to ascertain the presence or absence of physiologic changes in the tissue with time, or when physiologic changes have occurred based on the inspection of a comparable tissue. The equivalent viewing direction can compensate for changes in the tissue in the body with time and/or can compensate for the symmetry and asymmetry of viewing projection images of different tissues in the body.

The term 'identifies' refers to a 3D or 2D image corresponding to a view that is displayed and/or compared with other views that reveals or more clearly elucidates a microcalcification or obstruction through one or more processes selected from the group consisting of: observation by the human eye, identification by a segmentation algorithm, identification by a bricking algorithm. The phrase 'improves the visual clarity of identification' means a process or technique that compares or changes one or more projection images to allow an obstruction including a microcalcification to be identified in the one or more projection images.

Receiving a Volumetric Image

A computed tomography (CT) scan can generate many 2-D images taken from different angles around a scanned object to produce cross-sectional (tomographic) images ('virtual slices') of the scanned object. Alternatively, positron emission tomography (PET), single photon emission computed tomography (SPECT), computer assisted tomography (CAT) scanners or tomosynthesis systems can produce 'measured projection images'. These measured 2-D projection images can be used to reconstruct a 'volumetric image', where the virtual slices form a volumetric image or 3-D image of the scanned object. The phrase 'volumetric image' refers to a 3-D representation reconstructed from the data produced by forward-projecting or back-projecting medical imaging equipment. Measured projection images can be measured by medical technologists, and can be used to reconstruct a volumetric image and then the volumetric image can be received by a physician in order to diagnose a patient.

In an embodiment of the invention, using the reconstructed 3-D image it is possible to form a generated 2-D projection image, that is, a representation can be generated from a volumetric image by identifying a point source at a distinct focus and thereby a 'projection direction' through the volume to a plane at which the respective generated 2-D projection image can be formed.

Computing a Plurality of Projection Images

One or more generated 2-D projection images can be generated from a volumetric image. Computing a plurality of generated 2-D projection images of the volumetric image using a plurality of viewing directions between a first viewing direction and a second viewing direction can be used to produce generated 2-D projection images required by a physician but otherwise not revealed by a measured 2-D projection image. Alternatively, by generating a plurality of generated 2-D projection images, a dynamic view of the volumetric image can be generated, which allows for better diagnosis than a single or static measured 2-D projection image or a single or static generated 2-D projection image. Comparing a First Projection Image a Second Projection Image

The phrase 'time comparison' means comparing a projection image obtained at a specific viewing direction with an earlier in time projection image of a tissue obtained at an equivalent viewing direction of the same tissue. In an embodiment of the invention, a time comparison compares one or more projection images of a right breast with one or more projection images of the same right breast measured at an earlier time point, where the projection images are generated at equivalent viewing directions. In an embodiment of the invention, a time comparison compares one or more measured 2-D projection images of a right breast with one or more generated 2-D projection images of the same right breast generated from a volumetric image reconstructed from a plurality of measured 2-D projection images from an earlier time point, where the projection images are generated at equivalent viewing directions. In an alternative embodiment of the invention, a time comparison compares one or more generated 2-D projection images of a right breast with one or more measured 2-D projection images of the same right breast measured at an earlier time point, where the projection images are generated at equivalent viewing directions.

The phrase 'structural comparison' means comparing a projection image obtained at a specific viewing direction with a projection image of a tissue obtained at an equivalent viewing direction of a different but comparable tissue. In an embodiment of the invention, a structural comparison com-

compares one or more projection images of a right breast with one or more projection images of a left breast both viewed at equivalent viewing directions. In an embodiment of the invention, a structural comparison compares one or more generated 2-D projection images of a right breast with one or more generated 2-D projection images of a left breast, where each of the generated 2-D projection images are viewed at equivalent viewing directions. In an alternative embodiment of the invention, a structural comparison compares one or more measured 2-D projection images of a right breast with one or more generated 2-D projection images of a left breast, where each of the measured and generated 2-D projection images are viewed at equivalent viewing directions. In another embodiment of the invention, a structural comparison compares one or more generated 2-D projection images of a right breast with one or more measured 2-D projection images of a left breast, where each of the measured and generated 2-D projection images are viewed at equivalent viewing directions.

The phrase 'dynamic comparison' means comparing a series of projection images obtained at a variety of viewing directions. In an embodiment of the invention, a dynamic comparison compares one or more DBT projection images of a right breast that change in time as the viewing direction is scanned as a video. In an embodiment of the invention, the change in viewing direction can adjust for the type of tissue being scanned.

The phrase 'visual comparison' means time comparing, structurally comparing, and/or dynamically comparing one or more projection images with the naked eye.

The phrase 'direct comparison' means one or more of time comparing, structurally comparing, and dynamically comparing one or more projection images using a computer to analyze changes in the intensity density of a voxel matrix represented by the projection images. In an embodiment of the invention, one or more generated 2-D projection images are compared with one or more measured 2-D projection images using one or more of time comparing, structurally comparing, and dynamically comparing, wherein a computer is used to analyze changes in the intensity density of a voxel matrix represented by the one or more generated 2-D projection images and the one or more measured 2-D projection images.

A first viewing direction **111** corresponds with the line between position **110** and the object **105**. A second viewing direction **116** corresponds with line between position **115** and the object **105** (see FIG. 1A). The increment **112** is the angle between the first viewing direction **111** and the second viewing direction **112** (see FIG. 1A). By selecting a first viewing direction, a first generated 2-D projection image can be formed. Similarly, selecting a second viewing direction allows a second generated 2-D projection image at the second viewing direction to be formed. In an embodiment of the invention a first generated 2-D projection image can be dynamically compared with one or more second generated 2-D projection images. In an alternative embodiment of the invention a measured 2-D projection image can be dynamically compared with one or more generated 2-D projection images. In an alternative embodiment of the invention, a first projection image can be time compared with a second projection image measured at an earlier time. In another embodiment of the invention, a generated 2-D projection image can be time compared with a measured 2-D projection image measured at an earlier time. In another embodiment of the invention, a first projection image can be structurally compared with a second projection image of a control tissue. In another embodiment of the invention, a generated 2-D

projection image can be structurally compared with a measured 2-D projection image of a control tissue. In an embodiment of the invention, a density map for the first projection image is visually compared with a density map of the second projection image. In an embodiment of the invention, a density map for a generated 2-D projection image is visually compared with a density map of a measured 2-D projection image. In an alternative embodiment of the invention, a computer program is used to directly compare the density map for the first projection image with a density map of the second projection image. In another alternative embodiment of the invention, a computer program is used to directly compare the density map for a generated 2-D projection image with a density map of a measured 2-D projection image.

#### Volume Rendering

Volume rendering, or reconstructing a volume, includes a variety of standard visualization methods including volume rendering techniques (VRT), shaded volume rendering techniques (sVRT), maximum intensity projection (MIP), oblique slicing or multiplanar reformats (MPR), axial/sagittal and coronal slice display, and thick slices (also called slabs). Within the scope of the invention, other methods and apparatus of forward-projection and back-projection can be used for generating a series of measured 2-D projection images with which to reconstruct 3-D volumetric image representations, as described in U.S. Pat. No. 9,019,287, which is herein expressly incorporated by reference in its entirety.

In an embodiment of the invention, a computer chip, chip set, computer board and/or computer processor can be configured as a 'graphics processing unit' (GPU) to perform volume rendering and or to generate one or more reconstructed 2-D projection views from a volumetric image. In an embodiment of the invention, volume rendering includes initializing to arbitrary values the volume density distribution in a voxel matrix, iteratively estimating and comparing with a measured projection, and then correcting each pixel based on the comparison as described in U.S. Pat. No. 7,876,944.

#### Intensity Values

Image segmentation is an automated technique that facilitates distinguishing objects and other features in digital images. The technique can be used, for example, to simplify digitized images so that they can be more readily interpreted by computers (e.g., image analysis software) and/or by their users. An image can be made up of pixels containing a wide range of undifferentiated intensity values that although, possibly recognizable to the human eye as skeletal bones and digestive tract are largely uninterpretable by a computer. In an embodiment of the invention, a comparison between a first projection image with a second projection image that reveals an area of increased intensity values in the second projection image can indicate that the second viewing direction which generated the second projection image reveals an unobstructed projection image. In an alternative embodiment of the invention, a comparison between a generated 2-D projection image with a measured 2-D projection image that reveals an area of increased differentiated intensity values in the measured 2-D projection image can indicate that the viewing direction which formed the generated 2-D projection image reveals an unobstructed viewing direction. In an alternative embodiment of the invention, a comparison between a first projection image with a second projection image that reveals an area of increased differentiated intensity values in the second projection image can indicate that the second viewing direction which generated the second

projection image reveals an increased clarity projection image, as described in U.S. Pat. No. 8,548,215, which is herein expressly incorporated by reference in its entirety. In an alternative embodiment of the invention, a comparison between a generated 2-D projection image with a measured 2-D projection image that reveals an area of increased differentiated intensity values in the measured 2-D projection image can indicate that the viewing direction which formed the generated 2-D projection image reveals an advantageous viewing direction.

#### Primary Study Versus Secondary Study

A primary study is a study carried out at a specified time point. A secondary study is a study carried out at a subsequent time point. In an embodiment of the invention, a computer chip, chip set, computer board and/or computer processor can be configured as a 'digital data processor' to perform volume rendering, to generate one or more projection views from a volume and or to compare two or more projection views. The digital data is generated by forward-projecting or back-projecting medical imaging equipment used to generate measured projection images or other 2-D representations. In an embodiment of the invention, a comparison between a generated 2-D projection image from a secondary study with a generated 2-D projection image from a primary study that reveals an area of increased differentiated intensity values can be used to assess the development or changes occurring over time. In an embodiment of the invention, a comparison between a generated 2-D projection image from a secondary study with a measured 2-D projection image from a primary study that reveals an area of increased differentiated intensity values in the measured 2-D projection image can indicate that the viewing direction which formed the generated 2-D projection image reveals an unobstructed viewing direction.

In the following description, various aspects of the present invention will be described. However, it will be apparent to those skilled in the art that the present invention may be practiced with only some or all aspects of the present invention. For purposes of explanation, specific numbers, materials, and configurations are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced without the specific details. In other instances, well-known features are omitted or simplified in order not to obscure the present invention.

Parts of the description will be presented in data processing terms, such as data, selection, retrieval, generation, and so forth, consistent with the manner commonly employed by those skilled in the art to convey the substance of their work to others skilled in the art. As is well understood by those skilled in the art, these quantities (data, selection, retrieval, generation) take the form of electrical, magnetic, or optical signals capable of being stored, transferred, combined, and otherwise manipulated through electrical, optical, and/or biological components of a processor and its subsystems.

Various operations will be described as multiple discrete steps in turn, in a manner that is most helpful in understanding the present invention; however, the order of description should not be construed as to imply that these operations are necessarily order dependent.

Various embodiments will be illustrated in terms of exemplary classes and/or objects in an object-oriented programming paradigm. It will be apparent to one skilled in the art that the present invention can be practiced using any number of different classes/objects, not merely those included here for illustrative purposes. Furthermore, it will also be appar-

ent that the present invention is not limited to any particular software programming language or programming paradigm.

Due to the physical constraints of the acquisition setup, the possible angular range of the acquisition is often limited. Typically the angular range **112** is less than  $180^\circ$  in digital breast tomosynthesis (DBT) (see FIG. 1A). For mathematical reasons, this results in volumetric images with a non-isotropic resolution. More precisely, the resolution in the plane perpendicular to the average projection direction is much higher, than the reconstructed resolution in the average direction of the X-Ray beam.

This aspect has to be taken into account when designing viewing methods for such images. Given the reconstructed volumetric image, in the following the direction of the lowest resolution will be referred to as the z-direction, or  $\underline{z}$ . The vectors defining the average detector orientation, i.e. the plane with the highest resolution are denoted as  $\underline{x}$ , and  $\underline{y}$ . The  $\underline{x}$ ,  $\underline{y}$ , and  $\underline{z}$  directions are mutually perpendicular to each other.

In order to display a volumetric image on a standard computer screen, which is two dimensional, a transformation has to be applied in order to compute a 2-D representation of the volumetric image.

For DBT viewing, a slicing transformation can be used, where a single slice perpendicular to the z-direction is shown on the screen. Typically a user interface, such as a slider or text input field, allows the user to select which slice can be shown. In the following this will be referred to as 'xy-slicing' or 'slicing'. While xy-slicing is an important viewing tool, it has some limitations. In particular it only takes into account a small subset of the information present in the volumetric data set.

The present invention overcomes the limitation of using only a small subset of the information by using a projection method to incorporate the entirety of the volumetric information. In an embodiment of the present invention, time is used as a third dimension to resolve ambiguities in a comprehensible and intuitive way.

From the volumetric image a projection can be computed.

Let

$I: \mathbb{R}^3 \rightarrow \mathbb{R}$  be the volumetric image.

Let  $\underline{v} \in \mathbb{R}^3$  be a three dimensional vector defining a first viewing direction.

Let  $\underline{i}_x$  and  $\underline{i}_y$  be two vectors spanning a projection plane perpendicular to  $\underline{v}$  and perpendicular to each other.

Then a projection  $P(\underline{v}, \cdot)$  can be defined as follows:

$P(\underline{v}, \cdot): \mathbb{R}^2 \rightarrow \mathbb{R}$

$P(\underline{v}, \underline{p}) = \max(I(\underline{r})) | \underline{r} \in \mathbb{R}^3, \underline{v} \cdot \underline{i}_x = \underline{p}_1, \underline{v} \cdot \underline{i}_y = \underline{p}_2$  and  $P(\underline{v}, \cdot)$  is a 2D image that can be displayed on a computer screen using standard methods.

Displaying  $P(\underline{v}, \cdot)$  as defined above provides the user with additional diagnostic information as it takes into account the whole data set. For example if there was a lesion in the examined specimen and the volumetric image was viewed using xy-slicing then that lesion would only be visible in a subset of the slices at or around the z-position of the lesion. If the wrong z-position was chosen, the lesion can be missed. Therefore the user would have to examine each slice to be certain there was no lesion present, or alternatively risk overlooking a lesion. In an unexpected result, viewing a dynamic comparison in the form of a video can allow the information to be quickly and efficiently compared.

FIG. 1A shows a specimen **105** imaged from two positions **110**, **115** spanning an angular range **112** which generate viewing directions **111**, **116** respectively. FIG. 1B shows the principle of DBT. In FIG. 1B, the specimen **105** (e.g. a human breast) can be imaged using an X-Ray source and an

X-Ray detector from a multitude of positions that lie on the arc beginning at position 110 and ending at position 115 and which are detected at detector positions 120 and 125, respectively. The average acquisition direction is indicated by the dotted line 130. The positions span a certain angular range that is defined by the physical constraints of the machine and the patient's position. The z vector ( $\underline{z}$ ) 130 denotes the middle projection direction in that angular range. FIG. 2 illustrates the calculation of a projection P from the volumetric image I, 235. The projection is defined by the viewing direction  $\underline{v}$  245, which defines the projection plane 240. In general  $\underline{v}$  245 is not necessarily identical to the average acquisition direction  $\underline{z}$  250. The two vectors  $\underline{i}_x$  252 and  $\underline{i}_y$  254 are the x-direction and y-direction of the projection image P, respectively. The vectors  $\underline{i}_x$  252 and  $\underline{i}_y$  254 are perpendicular to the viewing direction  $\underline{v}$  245. The vector  $\underline{i}_x$  252 is perpendicular to the vector  $\underline{i}_y$  254, and can be chosen according to the users viewing preferences or automatically specified according to automated rules, as described in more detail in "Method and System for Rule-Based Display of Sets of Images" issued as U.S. Pat. No. 8,976,190. Digital Imaging and Communication in Medicine (DICOM) parameters for making rule based decisions include the time of generation of the measured projection images, the type of tissue measured and whether the tissue has an equivalent control that can be used as a control. For example for mediolateral acquisition directions, the y-axis will typically be chosen such that it aligns with the projection of the patient's head-foot axis.

Instead, when looking at the projection image P( $\underline{v}$ ,.), an area of increased density, such as a lesion or calcification will appear as a brighter spot, irrespective of its z-position, making it possible to detect in many cases. FIG. 7A shows an artists impression of an image of a human breast computed from a number of 2D X-Ray images produced by a DBT device taken from a specific angle where a micro calcification is occluded by denser breast tissue. In FIG. 7A a region 774 is identified. FIG. 7B shows an artists impression of an image of a human breast taken from a different angle to that shown in FIG. 7A. Comparison of FIG. 7A and FIG. 7B show a micro calcification is visible in FIG. 7B when the tissue is not occluded by denser breast tissue. Unexpectedly, in FIG. 7B the region 774 which was identified in FIG. 7A shows a micro calcification is visible and not occluded by the denser breast tissue.

FIGS. 8A-8D show an artists impression of four (4) images which make up time points in a mp3 video of a dynamic comparison of DBT of a right breast while the viewing direction changes, according to an embodiment of the invention. The mp3 video used to generate FIGS. 8A-8D had a duration of approximately 13 seconds. Unexpectedly, the mp3 video is an excellent means of inspecting DBTs to identify micro calcifications. FIG. 8A shows the artists impression of a screen dump from the mp3 video at approximately the two (2) second time point. FIG. 8B shows the artists impression of a screen dump from the mp3 video at approximately the five (5) second time point. FIG. 8C shows the artists impression of a screen dump from the mp3 video at approximately the nine (9) second time point. FIG. 8D shows the artists impression of a screen dump from the mp3 video at approximately the twelve (12) second time point. The dynamic comparison illustrates the differences between the intensity of the voxel matrix from which the projection image is calculated. Unexpectedly, when viewing the video a spot becomes apparent, which is shown in FIG. 8B and FIG. 8C but is not present in FIG. 8A or FIG. 8D. FIG. 9A shows an enlarged version of FIG. 8B, the artists impression

of the screen dump from the mp3 video at approximately the five (5) second time point where the region 774 is identified. FIG. 9B shows an enlarged version of FIG. 8C, the artists impression of the screen dump from the mp3 video at approximately the nine (9) second time point where the region 774 is again identified. The spot seen in FIG. 8B (FIG. 9A) and FIG. 8C (FIG. 9B) reduces in intensity between the observation in FIG. 8B (FIG. 9A) and the observation in FIG. 8C (FIG. 9B). Unexpectedly, the emergence and dimution of a relatively bright spot in the same position when viewing a video, can also be used to confirm a microcalcification rather than an artifact of the imaging system. Thus, based on the mp3 video a microcalcification 774 jumps to the viewer's attention by way of the nature of the dynamic comparison, as shown in the difference between FIG. 8A where no microcalcification is present and FIG. 8B (FIG. 9A) where the microcalcification, 774 is present. Viewing the mp3 video improves the visual clarity of identification of a micro calcification.

FIG. 10A shows the image of a human breast generated from a volumetric image reconstructed from a number of 2D X-Ray images produced by a DBT device, where the generated 2-D projection image was formed at a specific angle, where a micro calcification is occluded by denser breast tissue, as represented in FIG. 7A. FIG. 10B shows the generated 2-D projection image of the human breast formed from a different angle to that shown in FIG. 10A, where the micro calcification is visible and not occluded by the denser breast tissue, as represented in FIG. 7B. FIGS. 11A-11D show four (4) images which make up time points in the mp3 video of the dynamic comparison of the DBT of the right breast. FIG. 11A shows a screen dump from the mp3 video at a two (2) second time point, as represented in FIG. 8A. FIG. 11B shows a screen dump from the mp3 video at the five (5) second time point, as represented in FIG. 8B. FIG. 11C shows a screen dump from the mp3 video at the nine (9) second time point, as represented in FIG. 8C. FIG. 11D shows a screen dump from the mp3 video at the twelve (12) second time point, as represented in FIG. 8D. FIG. 12A shows an enlarged version of FIG. 11B, the screen dump from the mp3 video at the five (5) second time point where the region 774 is identified, as represented in FIG. 9A. FIG. 12B shows an enlarged version of FIG. 11C, the screen dump from the mp3 video at the nine (9) second time point where the region 774 is identified, as represented in FIG. 9B.

A draw-back of any projection method, is that there can be an occlusion or overlay effect. In the case of a maximum intensity projection as defined above, consider the case where two (2) separate areas of increased density are at different z positions on approximately the same viewing ray  $\underline{v}$ . FIG. 3A shows a specimen 356 with two separate areas 353 and 355 of increased density. In the projection they will appear as one, potentially larger spot. That is, for one viewing direction ( $\underline{v}_1$ ) 358 the two separate areas 353 and 355 can be projected to the same spot in the projection image (projection 1) shown in FIG. 3B.

In an embodiment of the present invention, this ambiguity can be resolved by making the projection dynamic. Instead of choosing a fixed viewing direction  $\underline{v}$ , a dynamic viewing direction can be used. Using an alternative viewing direction ( $\underline{v}_2$ ) 360, the two separate areas 353 and 355 project to different spots in the projection image, making it obvious that there are two areas of interest. FIG. 3C shows for the second viewing direction ( $\underline{v}_2$ ) 360 the two separate areas 353 and 355 can be projected to different spots in the generated 2-D projection image (projection 2).

In an alternative embodiment of the invention, different dynamic functions can be used to generate dynamic projection viewing directions. Given the non-isotropy of the input data mentioned above, the most useful dynamic functions are continuous periodic functions around the z direction. Two non-limiting examples of dynamic functions include:

$$v(t)=\text{normalize}(z+A \sin(\omega t)\underline{x}) \quad \text{Equation 1}$$

$$v(t)=\text{normalize}(z+A \sin(\omega t)\underline{x}+A \cos(\omega t)\underline{y}) \quad \text{Equation 2}$$

where  $\text{normalize}(\underline{v})=\underline{v}/|\underline{v}|$ ; t: time;  $\omega=2\pi f$ ; f: frequency of the dynamic movement and A: Amplitude of the dynamic movement, e.g.  $A=0.05$ .

In other embodiments of the invention, different alternative dynamic functions can be used to generate dynamic projection viewing directions. In an embodiment of the invention, a linear function can be used in which the angle can be changed linearly. In an alternative embodiment of the invention, a z direction can be chosen and either the x or the y direction can be incremented. FIG. 6 illustrates the dynamic variation of the viewing direction  $\underline{v}$  according to Equation 2. The viewing direction at two different points  $\underline{v}_{t_1}$  **666** and  $\underline{v}_{t_2}$  **668** at time  $t_1$  and  $t_2$  is shown, as well as the corresponding projection planes projection plane ( $t_1$ ) **670** and projection plane ( $t_2$ ) **672**. Over time the viewing direction  $\underline{v}$  can be varied around the main acquisition direction  $\underline{z}$  **130**.

In another embodiment of the invention, the viewing direction can be determined by the user. In another alternative embodiment of the invention, the viewing direction can be determined by the user with an appropriate input device, such as a mouse. In an embodiment of the present invention, let  $(m_{x1}, m_{y1})$  be the position of the mouse (or appropriate input device) at a starting time  $t_1$ . The starting time can then be defined by a mouse click (or appropriate input device). In an alternative embodiment of the present invention, the starting time can be triggered by the user entering a certain window with the mouse (or appropriate input device), or other graphical or non graphical criteria.

Assuming the user is moving the mouse, let  $(m_{x2}, m_{y2})$  be the position of the mouse (or appropriate input device) at time  $t_2$ . Let  $s_{width}$  and  $s_{height}$  be the width and height of the screen.

Then  $v(t_2)=\text{normalize}(z+2 A \underline{x} (m_{x2}-m_{x1})/s_{width}+2 A \underline{y} (m_{y2}-m_{y1})/s_{height})$  can be the interactively controlled viewing direction at time  $t_2$ . A person of ordinary skill in the art will appreciate that alternative mappings from the mouse coordinates to viewing directions can be used. In various embodiments of the present invention, alternative input methods or devices can be used including, a slider, a trackball, a head tracking device or an eye tracking device.

The above projection is a maximum intensity projection.

In various other embodiments of the present invention, other projection functions can be used, including emission absorption models or minimum intensity projections. The above projection is equivalent to an orthographic projection, where a 3-D object is represented in two dimensions through parallel projection, where all the projection lines are orthogonal to the projection plane. A person of ordinary skill in the art will appreciate that alternative projections including perspective projections can be used.

In an embodiment of the invention, an optimal viewing direction can be selected by comparing the resulting projection images at a plurality of viewing directions. In an embodiment of the invention, the criterion used for determining the optimal viewing direction can be a viewing direction that identifies an unobserved obstruction. In an

alternative embodiment of the invention, the criterion used for determining the optimal viewing direction can be a viewing direction that improves the visual clarity of an initial projection image. In another alternative embodiment of the invention, the criterion used for determining the optimal viewing direction can be a viewing direction that improves the visual clarity of an improved projection image compared with an initial projected image. In a different embodiment of the invention, the criterion used for determining the optimal viewing direction can be a viewing direction that improves the visual clarity of identification of an obstruction. In another different embodiment of the invention, the criterion used for determining the optimal viewing direction can be a viewing direction that identifies an obstruction using direct comparison. In another embodiment of the invention, the criterion used for determining the optimal viewing direction can be a viewing direction that improves the direct comparison clarity of an initial projection image. In an embodiment of the invention, the criterion used for determining the optimal viewing direction can be a viewing direction that improves the direct comparison clarity of an improved projection image compared with an initial projected image. In another embodiment of the invention, the criterion used for determining the optimal viewing direction can be a viewing direction that improves the direct comparison clarity of identification of an obstruction.

Volumetric images in DBT are quite large data sets, as the xy-resolution is an order of magnitude larger than for example a standard CT scan. In order to render such large images at interactive speeds graphics processing units (GPU) can be utilized, see for example Methods and Apparatus for Visualizing Three-Dimensional and Higher-Dimensional Image Data Sets, U.S. Pat. No. 8,189,002, which is herein expressly incorporated by reference in its entirety. In typical DBT images, only a subset of the voxels of the volumetric image contain tissue, while other voxels are background pixels that are irrelevant for the diagnosis. In an embodiment of the present invention, by using a threshold segmentation these background pixels can be identified. FIG. 4 shows how only a subset of the acquisition volume is covered by the specimen **462**, while other areas (hatched) **464** only contain background pixels. These background pixels can be identified using threshold segmentation. FIG. 5 shows the volume can be subdivided into sub-volumes. In one embodiment of the invention, an octree decomposition scheme can be used for this subdivision. In another embodiment of the invention, a binary space partitioning (BSP) scheme can be used for the subdivision. A person with ordinary skills in the art will appreciate that other subdivision schemes can be used. Sub-volumes that contain only background voxels (shown as hatched in FIG. 4 and FIG. 5) **464** can be skipped during the rendering process. Sub-volumes **463** that contain both, background voxels and tissue voxels can be further subdivided until a configured minimum size containing specimen **462** or background **464** can be reached. In an embodiment of the invention, bricking can be used to display only those sub-volumes that are not background-only. The technique of bricking for GPU based rendering is described in U.S. Pat. No. 8,189,002.

In an embodiment of the present invention, for the effective use of dynamic projection images, a sufficiently high frame rate is required in order to allow for a smooth rendering that appears natural to the user. This can be achieved in many cases by using GPU hardware combined with the bricking technique.

In an alternative embodiment of the present invention, a periodic dynamic viewing direction function can be used,

and a sequence of projections covering one full period (1/f) can be pre-rendered, and then be played back in a loop. In case of a client server visualization system, the pre-rendered images can be computed on the server side and cached on the client side thereby making optimal use of the bandwidth and allowing for smooth playback even on slow networks.

In radiological diagnostics, comparison to prior images is relevant to detect change, e.g. tumor growth. In an embodiment of the present invention, a projection of a current image and a projection of a corresponding prior image can be displayed side-by-side and used to determine the change in tumor characteristics. The comparison can include the user visually comparing with the naked eye. The comparison can also be undertaken by a direct comparison program where equivalent viewing directions are used for the direct comparison. In various embodiments of the present invention, the user can choose the same dynamic viewing direction function for both, the current and the prior image, thereby allowing for direct comparison.

Another aspect of the invention is to combine the projection display of the volumetric image with conventional 2D mammograms or other X-Ray or radiological images, by dividing the available computer screens into virtual view ports and using one or more of the virtual view ports to display the one or more projection images, and one or more of the virtual viewports to display the other radiological images.

A method for displaying one or more optimal projection images generated from a volumetric image comprising the steps of receiving the volumetric image, computing a plurality of projection images of the volumetric image using a plurality of viewing directions, where at least an initial projection image of the plurality of projection images is computed using a first viewing direction, where a second viewing direction of the plurality of viewing directions is not equal to the first viewing direction, one or more of time comparing, structurally comparing and dynamically comparing the plurality of projection images to determine one or more optimal projection images and displaying the optimal projection images.

A method for identifying one or more optimal projection images generated from a volumetric image comprising the steps of receiving the volumetric image, computing a plurality of projection images of the volumetric image using a plurality of viewing directions, where at least an initial projection image of the plurality of projection images is computed using a first viewing direction, where a second viewing direction of the plurality of viewing directions is not equal to the first viewing direction, and one or more of time comparing, structurally comparing and dynamically comparing the plurality of projection images to determine one or more optimal projection images.

A method for identifying one or more optimal projection images generated from a volumetric image comprising the steps of receiving the volumetric image, computing a plurality of projection images of the volumetric image using a plurality of viewing directions, where at least an initial projection image of the plurality of projection images is computed using a first viewing direction, where a second viewing direction of the plurality of viewing directions is not equal to the first viewing direction, and one or more of time comparing, structurally comparing and dynamically comparing the plurality of projection images to determine one or more optimal projection images, where the optimal viewing direction is selected from the group consisting of a viewing direction that identifies an unobserved obstruction, a viewing direction that improves the visual clarity of the first

projection image, a viewing direction that improves the visual clarity of the second projection image, a viewing direction that improves the visual clarity of identification of an obstruction, a viewing direction that identifies an obstruction using direct comparison, a viewing direction that increases the differentiated intensity values of the first projection image, a viewing direction that increases the differentiated intensity values of the second projection image, a viewing direction that improves the direct comparison clarity of the first projection image, a viewing direction that improves the direct comparison clarity of the second projection image, and a viewing direction that improves the direct comparison clarity of identification of an obstruction.

A method to determine one or more optimal projection images from a volumetric image comprising the steps of receiving a volumetric image, computing a plurality of projection images based on the volumetric image using a plurality of viewing directions, one or more of time comparing, structurally comparing and dynamically comparing the plurality of projection images to determine one or more optimal viewing directions, and correlating the optimal viewing directions with one or more projection images of the plurality of projection images to determine one or more optimal projection images.

A method to determine one or more optimal projection images from a volumetric image comprising the steps of receiving a volumetric image, computing a plurality of projection images based on the volumetric image using a plurality of viewing directions, one or more of time comparing, structurally comparing and dynamically comparing the plurality of projection images to determine one or more optimal viewing directions, and correlating the optimal viewing directions with one or more projection images of the plurality of projection images to determine one or more optimal projection images, where the optimal viewing direction is selected from the group consisting of a viewing direction that identifies an unobserved obstruction, a viewing direction that improves the visual clarity of the first projection image, a viewing direction that improves the visual clarity of the second projection image, a viewing direction that improves the visual clarity of identification of an obstruction, a viewing direction that identifies an obstruction using direct comparison, a viewing direction that improves the direct comparison clarity of the first projection image, a viewing direction that improves the direct comparison clarity of the second projection image, and a viewing direction that improves the direct comparison clarity of identification of an obstruction.

A method to determine one or more optimal projection images from a volumetric image comprising the steps of receiving a volumetric image, computing a plurality of projection images based on the volumetric image using a plurality of viewing directions, one or more of time comparing, structurally comparing and dynamically comparing the plurality of projection images to determine one or more optimal viewing directions, and correlating the optimal viewing directions with one or more projection images of the plurality of projection images to determine one or more optimal projection images, where the volumetric image is a 3D image.

A method to determine one or more optimal projection images from a volumetric image comprising the steps of receiving a volumetric image, computing a plurality of projection images based on the volumetric image using a plurality of viewing directions, one or more of time comparing, structurally comparing and dynamically comparing







images of the three dimensional volumetric image of the tissue using a plurality of viewing directions, one or more of time comparing, structurally comparing and dynamically comparing the plurality of projection images, and identifying an object that is present in a projection image selected from the plurality of projection images that is not present in one or more of the one or more projection images selected from the plurality of projection images, where at least one of the plurality of viewing directions is determined using a periodic continuous mathematical function, where the plurality of projection images is a sequence of projection images spanning one period of the periodic continuous mathematical function, further comprising rendering and caching a sequence of projection images, where the rendered and cached sequence of projection images are played back one or more times.

A method for identifying an object in a projection image comprising the steps of receiving a three dimensional volumetric image of a tissue, computing a plurality of projection images of the three dimensional volumetric image of the tissue using a plurality of viewing directions, one or more of time comparing, structurally comparing and dynamically comparing the plurality of projection images, and identifying an object that is present in a projection image selected from the plurality of projection images that is not present in one or more of the one or more projection images selected from the plurality of projection images, where at least one of the plurality of viewing directions is determined using a periodic continuous mathematical function, where the plurality of projection images is a sequence of projection images spanning one period of the periodic continuous mathematical function, further comprising rendering and caching a sequence of projection images, where the rendering is carried out on a server.

A method for identifying an object in a projection image comprising the steps of receiving a three dimensional volumetric image of a tissue, computing a plurality of projection images of the three dimensional volumetric image of the tissue using a plurality of viewing directions, one or more of time comparing, structurally comparing and dynamically comparing the plurality of projection images, and identifying an object that is present in a projection image selected from the plurality of projection images that is not present in one or more of the one or more projection images selected from the plurality of projection images, where at least one of the plurality of viewing directions is determined using a periodic continuous mathematical function, where the plurality of projection images is a sequence of projection images spanning one period of the periodic continuous mathematical function, further comprising rendering and caching a sequence of projection images, where the caching is carried out on a client computer.

A method for identifying an object in a projection image comprising the steps of receiving a three dimensional volumetric image of a tissue, computing a plurality of projection images of the three dimensional volumetric image of the tissue using a plurality of viewing directions, one or more of time comparing, structurally comparing and dynamically comparing the plurality of projection images, and identifying an object that is present in a projection image selected from the plurality of projection images that is not present in one or more of the one or more projection images selected from the plurality of projection images, where at least one of the plurality of viewing directions is determined using a periodic continuous mathematical function, where the plurality of projection images is a sequence of projection images spanning one period of the periodic continuous

mathematical function, further comprising rendering and caching a sequence of projection images, where the rendering is carried out on a server, where the play back is carried out on a client computer.

A method for identifying an object in a projection image comprising the steps of receiving a three dimensional volumetric image of a tissue, computing a plurality of projection images of the three dimensional volumetric image of the tissue using a plurality of viewing directions, one or more of time comparing, structurally comparing and dynamically comparing the plurality of projection images, and identifying an object that is present in a projection image selected from the plurality of projection images that is not present in one or more of the one or more projection images selected from the plurality of projection images, where at least one of the plurality of viewing directions is determined using a periodic continuous mathematical function, where a graphics processing unit is used to compute one or more of the plurality of projection images.

A method for identifying an object in a projection image comprising the steps of receiving a three dimensional volumetric image of a tissue, computing a plurality of projection images of the three dimensional volumetric image of the tissue using a plurality of viewing directions, one or more of time comparing, structurally comparing and dynamically comparing the plurality of projection images, and identifying an object that is present in a projection image selected from the plurality of projection images that is not present in one or more of the one or more projection images selected from the plurality of projection images, where at least one of the plurality of viewing directions is determined using a periodic continuous mathematical function, where a graphics processing unit is used to compute one or more of the plurality of projection images, where bricking is used to accelerate computation of one or more of the plurality of projection images.

A method for identifying an optimal projection image comprising the steps of receiving a volumetric image, computing the plurality of projection images based on the volumetric image using a plurality of viewing directions, and comparing the plurality of projection images to determine an optimal viewing direction corresponding to an optimal projection image.

A method for identifying an optimal projection image comprising the steps of receiving a volumetric image, computing the plurality of projection images based on the volumetric image using a plurality of viewing directions, and comparing the plurality of projection images to determine an optimal viewing direction corresponding to an optimal projection image, where the optimal viewing direction is selected from the group consisting of a viewing direction that identifies an unobserved obstruction, a viewing direction that improves the visual clarity of the first projection image, a viewing direction that improves the visual clarity of the second projection image, a viewing direction that improves the visual clarity of identification of an obstruction, a viewing direction that identifies an obstruction using direct comparison, a viewing direction that improves the direct comparison clarity of the first projection image, a viewing direction that improves the direct comparison clarity of the second projection image, and a viewing direction that improves the direct comparison clarity of identification of an obstruction.

A method for displaying a plurality of projection images comprising the steps of receiving a volumetric image, computing the plurality of projection images based on the

volumetric image using a plurality of viewing directions and displaying the plurality of projection images.

A method for comparing a first projection image and a second projection image comprising the steps of receiving a volumetric image, computing the first projection image based on the volumetric image using a first viewing direction, computing the second projection image based on the volumetric image using a second viewing direction, where the first viewing direction is not equal to the second viewing direction and one or more of time comparing, structurally comparing and dynamically comparing the first projection image and the second projection image.

A method for comparing a first projection image and a second projection image comprising the steps of receiving a volumetric image, computing the first projection image based on the volumetric image using a first viewing direction, computing the second projection image based on the volumetric image using a second viewing direction, where the first viewing direction is not equal to the second viewing direction and one or more of time comparing, structurally comparing and dynamically comparing the first projection image and the second projection image, further comprising one or more steps selected from the group consisting of identifying visually an obstruction, improving the visual clarity of the first projection image, improving the visual clarity of the second projection image, improving the visual clarity of identification of an obstruction, identifying an obstruction using direct comparison, improving the direct comparison clarity of the first projection image, improving the direct comparison clarity of the second projection image, and improving the direct comparison clarity of identification of an obstruction.

A method for displaying one or more unobstructed projection images comprising the steps of receiving a volumetric image, computing a plurality of projection images based on the volumetric image using a plurality of viewing directions, where at least a first projection image of the plurality of projection images is computed using a first viewing direction and at least a second projection image of the plurality of projection images is computed using a second viewing direction, where the first viewing direction is not equal to the second viewing direction, one or more of time comparing, structurally comparing and dynamically comparing the first projection image and the second projection image to determine if one or both of the first projection image and the second projection image are unobstructed, and displaying based on the comparison one or both the first projection image and the second projection image.

A method for displaying an unobstructed projection image of a breast comprising the steps of receiving a volumetric image of the breast, computing a first projection image of the breast based on the volumetric image using a first viewing direction and a second projection image of the breast based on the volumetric image using a second viewing direction, where the first viewing direction is not equal to the second viewing direction, one or more of time comparing, structurally comparing and dynamically comparing the second projection image of the breast with the first projection image of the breast to determine if one or both the first projection image of the breast and second projection image of the breast is unobstructed, and based on the comparison displaying one or both the first projection image of the breast and second projection image of the breast.

A system for displaying unobstructed breast projection images comprising receiving a plurality of volumetric images of a breast, where a first volumetric image of the plurality of projection images is measured at a first time and

a second volumetric image of the plurality of projection images is measured at a second time, where the first time differs from the second time by a time interval, computing a first projection image from the first volumetric image measured at the first time using a first viewing direction, computing one or more projection images from the first volumetric image measured at the first time using one or more viewing directions, one or more of time comparing, structurally comparing and dynamically comparing the first projection image and the one or more projection images to determine an unobstructed viewing direction, where a second projection image corresponds with the one or more projection images at the unobstructed viewing direction, computing a third projection image from the second volumetric image measured at the second time using the unobstructed viewing direction, and displaying the second projection image and the third projection image.

A system for displaying unobstructed breast projection images comprising receiving a plurality of volumetric images of a breast, where a first volumetric image of the plurality of projection images is measured at a first time and a second volumetric image of the plurality of projection images is measured at a second time, where the first time differs from the second time by a time interval, computing a first projection image from the first volumetric image measured at the first time using a first viewing direction, computing one or more projection images from the first volumetric image measured at the first time using one or more viewing directions, one or more of time comparing, structurally comparing and dynamically comparing the first projection image and the one or more projection images to determine an unobstructed viewing direction, where a second projection image corresponds with the one or more projection images at the unobstructed viewing direction, computing a third projection image from the second volumetric image measured at the second time using the unobstructed viewing direction, and displaying the second projection image and the third projection image, further comprising computing a fourth projection image from the second volumetric image measured at the second time using the first viewing direction.

A method for identifying additional lesions in a tissue comprising the steps of computing a plurality of projection images of the tissue using a plurality of viewing directions, where a first projection image is computed using a first viewing direction and a second projection image is computed using a second viewing direction, displaying the first projection image and the second projection image, one or more of time comparing, structurally comparing and dynamically comparing the first projection image and the second projection image, visually identifying an intense spot that separates in the second projection image from the first projection image.

A system that displays a first projection image and a second projection image of a volumetric image comprising a processor responsive to a command to select a volumetric image one or more digital data processors capable of carrying out the steps including, computing a first projection image of the volumetric image using a first viewing direction, computing a second projection image of the volumetric image using a second viewing direction, and graphics resources for displaying the first projection image and the second projection image.

A system that compares a first projection image and a second projection image of a volumetric image comprising a processor responsive to a command to select a volumetric image, one or more digital data processors capable of

carrying out the steps including computing a first projection image of the volumetric image using a first viewing direction, computing a second projection image of the volumetric image using a second viewing direction, and graphics resources for comparing the first projection image and the second projection image.

A method for displaying one or more unobstructed projection images comprising the steps of receiving a volumetric image, computing a plurality of projection images based on the volumetric image using a plurality of viewing directions, where at least a first projection image of the plurality of projection images is computed using a first viewing direction and at least a second projection image of the plurality of projection images is computed using a second viewing direction, where the first viewing direction is not equal to the second viewing direction, one or more of time comparing, structurally comparing and dynamically comparing the first projection image and the second projection image to determine if one or both of the first projection image and the second projection image are unobstructed, and displaying based on the comparison one or both the first projection image and the second projection image.

A method of visualizing a dynamic comparison of a volumetric image comprising the steps of receiving the volumetric image, computing a plurality of projection images of the volumetric image using a plurality of viewing directions between a smallest viewing direction and a largest viewing direction, and displaying a video showing the plurality of projection images, where the viewing direction changes with time.

The term 'brick' or 'bricking' means partitioning a 3D image or a portion of the 3D image. Bricking is an iterative process involving determining the intensity of pixels in the 2D image based on the rule that all points in the 3D image data that are required for evaluating the intensities of the sample points along a ray passing through a brick are located within that brick. That is in an imaging apparatus having a CPU and a GPU with a plurality of programmable vertex shaders coupled to a plurality of programmable pixel shaders, the CPU partitions the 3D image into a plurality 'bricks' based on the vertex shaders and pixel shaders determining the intensities of one or more pixels in the 2D image as an iterative function of intensities of sample points in one or more bricks in the 3D image through which viewing rays associated with those pixels are passed, and where any two adjacent bricks preferably have a sufficient overlap such that all points in the 3D image data that are required for evaluating the intensities of the sample points along a ray passing through a brick are located within that brick.

The term 'view' or 'viewing' means a display of a 3D or 2D image.

The phrases 'viewing position' or 'viewing ray' refer to a display of a 3D or 2D image as observed from the viewing position or along a line defined by the viewing ray.

The term 'microcalcification' refers to small deposits of calcium typically seen in a breast mammogram which depending on shape, number, pattern and/or relative position can be used as an early and/or presenting sign of breast cancer.

The term 'obstruction' means a filling defect or other ductal abnormality, such as ductal ectasia, fibrocystic changes or a ductal irregularity such as can be observed with ductography of the breast including galactography and ductogalactography.

The foregoing description of embodiments of the methods, systems, and components of the present invention has been provided for the purposes of illustration and descrip-

tion. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations will be apparent to one of ordinary skill in the relevant arts. For example, steps performed in the embodiments of the invention disclosed can be performed in alternate orders, certain steps can be omitted, and additional steps can be added. The embodiments were chosen and described in order to best explain the principles of the invention and its practical application, thereby enabling others skilled in the art to understand the invention for various embodiments and with various modifications that are suited to the particular used contemplated. Other embodiments are possible and are covered by the invention. Such embodiments will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. The breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents. The invention is illustrated by way of example and not by way of limitation in the figures of the accompanying drawings in which like references indicate similar elements. It should be noted that references to 'an' or 'one' embodiment in this disclosure are not necessarily to the same embodiment, and such references mean at least one.

What is claimed:

1. A method of visualizing occlusions in an image comprising the steps of: providing a server computer including a graphics processing unit and a first memory, where the server computer:

- a) receives a 3-D volumetric image reconstructed from a plurality of measured 2-D projection images;
- b) computes three or more generated 2-D projection images based on three or more 3-D volumetric image viewing directions, where a first viewing direction generated by a first straight line drawn between a first position and an object is used to compute a first generated 2-D projection image, where the angle between the first straight line and the first viewing direction is given by  $\theta_0$ , where  $\theta_0$  is equal to zero, a second viewing direction generated by a second straight line drawn between a second position and the object is used to compute a second generated 2-D projection image, where the angle between the second straight line and the first viewing direction is given by  $\theta_1$ , and at least a third viewing direction generated by a third straight line drawn between a third position and the object is used to compute a third generated 2-D projection image, where the angle between the third straight line and the first viewing direction is  $\theta_2$ ;
- c) sends the three or more generated 2-D projection images and viewing instructions to a remote device which includes a graphics display unit and a second memory, where the three or more generated 2-D projection images are stored in the second memory; and
- d) displays the three or more generated 2-D projection images to enhance visualizations of occlusions, where the viewing instructions determine that the three or more generated 2-D projection images are displayed on the graphics display unit in time delay corresponding with one or both increasing and decreasing  $\theta$ .

2. The method of claim 1, where at least one generated 2-D projection image of the three or more generated 2-D projection images enhance one or more features selected from the group consisting of:

- i) a microcalcification;
- ii) an obstruction;
- iii) a microcalcification includes two or more microcalcifications;
- iv) an obstruction includes a microcalcification and an obstruction;
- v) an obstruction includes two or more obstructions;
- vi) a microcalcification using direct comparison; and
- vii) an obstruction using direct comparison.

3. The method of claim 1, where at least one generated 2-D projection image of the three or more generated 2-D projection images enhance one or more features selected from the group consisting of:

- i) identification of the first generated 2-D projection image;
- ii) identification of the second generated 2-D projection image;
- iii) identification of a microcalcification;
- iv) identification of an obstruction;
- v) resolution of two microcalcifications;
- vi) resolution of a microcalcification and an obstruction;
- vii) resolution of two obstructions;
- viii) direct comparison with the first generated 2-D projection image;
- ix) direct comparison with the second generated 2-D projection image;
- x) direct comparison of a microcalcification; and
- xi) direct comparison of an obstruction.

4. The method of claim 1, where the 3-D volumetric image is a Digital Breast Tomosynthesis image.

5. The method of claim 1, where the three or more generated 2-D projection images are displayed as a video.

6. The method of claim 5, where the video displays a dynamic comparison.

7. The method of claim 1, where one or both the first viewing direction and the second viewing direction are selected according to a periodic continuous mathematical function.

8. The method of claim 7, where the three or more generated 2-D projection images are generated from viewing directions spanning one period of the periodic continuous mathematical function.

9. The method of claim 1, further comprising receiving one or more rendered generated 2-D projection images.

10. The method of claim 9, where the rendering is carried out on a server.

11. The method of claim 1, where one or both the first memory and the second memory is a cache.

12. The method of claim 11, further comprising storing the viewing instructions in cache.

13. The method of claim 11, further comprising using the viewing instructions to format the three or more generated 2-D projection images as a video.

14. The method of claim 11, further comprising storing the viewing instructions in the second memory as an executable file to display the three or more generated 2-D projection images as a video.

15. A method of visualizing obstructions in an image comprising the steps of:

- providing a server computer including a graphics processing unit and a first memory, where the server computer:
  - a) receives a first 3-D volumetric image of a first tissue measured at a first time of measurement;
  - b) computes a plurality of generated 2-D projection images of the first 3-D volumetric image using a plurality of viewing directions;

c) compares the plurality of generated 2-D projection images to identify a first viewing direction that identifies an obstruction, where the first viewing direction corresponds with a first generated 2-D projection image;

d) receiving a second 3-D volumetric image, where the second 3-D volumetric image is selected from the group consisting of:

- (i) a second 3-D volumetric image of the first tissue measured before the first time of measurement;
- (ii) a second 3-D volumetric image of the first tissue measured after the first time of measurement;
- (iii) a second 3-D volumetric image of a second tissue measured at the first time of measurement, where the second 3-D volumetric image of the second tissue enables a structural comparison of the first 3-D volumetric image of first tissue;

(iv) a second 3-D volumetric image of a second tissue measured before the first time of measurement, where the second 3-D volumetric image of the second tissue enables a structural comparison with the first 3-D volumetric image of first tissue; and

(v) a second 3-D volumetric image of a second tissue measured after the first time of measurement, where the second 3-D volumetric image of the second tissue enables a structural comparison with the first 3-D volumetric image of first tissue; and

e) using an equivalent viewing direction to compute a second generated 2-D projection image;

f) sending the first generated 2-D projection image, the second generated 2-D projection image and viewing instructions to a remote display device which includes a graphics display unit and a second memory, where the first generated 2-D projection image, the second generated 2-D projection image and viewing instructions are stored on the second memory; and

g) displays the first generated 2-D projection image, the second generated 2-D projection image according to the viewing instructions to enhance visualization of the obstruction, where the viewing instructions determine an orientation of the second generated 2-D projection image with respect to the first generated 2-D projection image, when the first generated 2-D projection image and the second generated 2-D projection image are displayed on the graphics display unit.

16. The method of claim 15, where the first generated 2-D projection image enhances one or more features selected from the group consisting of:

- i) a microcalcification;
- ii) a microcalcification using direct comparison; and
- iii) an obstruction using direct comparison.

17. The method of claim 15, where the first generated 2-D projection image enhances one or more features selected from the group consisting of:

- i) visual clarity of the first generated 2-D projection image;
- ii) visual clarity of identification of a microcalcification;
- iii) visual clarity of identification of an obstruction;
- iv) a direct comparison clarity of the first generated 2-D projection image;
- v) direct comparison identification of a microcalcification; and
- vi) direct comparison clarity of identification of an obstruction.

18. The method of claim 15, where one or both the first 3-D volumetric image and the second 3-D volumetric image are Digital Breast Tomosynthesis images.

19. The method of claim 15, where the first tissue is a right breast and the second tissue is a left breast.

20. A system of visualizing obstructions in an image comprising:

- one or more client digital data processors; 5
- a server digital data processor in communications coupling with the one or more client digital data processors, the server digital data processor comprising one or more graphics processing units and an associated memory; 10
- a program, executing on the server digital data processor, the program computing a plurality of generated 2-D projection images of a 3-D Digital Breast Tomosynthesis volumetric image using a plurality of viewing directions and caching the plurality of generated 2-D 15 projection images in the associated memory;
- analyzing one or more generated 2-D projection images using bricking to identify changes in intensity density of a plurality of voxel matrices representing the plurality of generated 2-D projection images to select three 20 or more generated 2-D projection images at varying viewing directions which enhance identification of an obstruction; and
- displaying on the one or more client digital data processors the three or more generated 2-D projection images 25 as a dynamic comparison.

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